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ECL 166A

MOVING MAP DISPLAY (A)

Bob Vago had the job to quickly produce a prototype of an improved Moving Map Display. This is a complex device which automatically shows position and heading of a plane on a map which moves as the plane flies. Optical, electrical, and mechanical subsystems are used. Bob's company originally intended to use a British license and American technology, but later decided to proceed to a novel design. Within a year a prototype was delivered. Fours years later production models were sold.

Part A gives the background; Part B shows Bob's design; Part C relates some of the difficulties which Bob had to surmount with the prototype; Part D shows the production model and an epilogue.

Prepared by Professor G. Kardos with support by the National Science Foundation with cooperation and information from Computing Devices of Canada Ltd.

MOVING MAP DISPLAY (A)
COMPUTING DEVICES OF CANADA LTD.

In 1962 Wing Commander Lambert R.A.F. (retired) proposed that Computing Devices of Canada Ltd. build a moving map display. At that time there existed a moving map display built by Mr. Honick of the Royal Aircraft Establishment, Farnborough, with which the Wing Commander had been associated. It was proposed that Computing Devices obtain from the Ministry of Aviation a license to build the Honick display. The intent was to ensure a ready acceptance of the Computing Devices display by the R.A.F. Additionally, it was reasoned that utilization of North American design techniques would lead to a much smaller and, therefore, more acceptable version of the Honick display.

Wing Commander Lambert had recently joined the British subsidiary of Computing Devices of Canada Ltd. (ComDev) as sales manager. Wing Commander Lambert had been a pilot with the R.A.F. He had originated the idea of a moving map display navigation aid while with the R.A.F. and had been instrumental in having the Honick display designed to meet his operational requirements. Honick, the designer, had patented many features of the display.

When Lambert joined ComDev he proposed that they undertake the manufacture of the display under license. Throughout the development Wing Commander Lambert was in charge of marketing of the unit and had a profound influence on performance requirements. His contacts within the Ministry of Aviation were invaluable in guiding the progress of the project.

The Project was assigned to Bob Vago, an electronic design engineer, "It seemed the programme was straightforward and plans were laid to produce a fully working model for flight trial at Boscombe Down in England."

The license agreement with the Minister of Aviation (M.O.A.) and a letter from the Wing Commander detailing the required operational performance was made available. Soon afterwards, it was learned that the M.O.A. had also licensed several other companies in the U.K. The most important of these licenses turned out to be Ferranti of Edinburgh. Ferranti had been working ahead of ComDev for some time with plans to provide the R.A.F. with the Honick Displays.

Computing Devices of Canada Ltd. is a Bendix Corporation affiliate located at Bells Corner, Ontario, just outside of Ottawa. Over a third of their 1500 staff are scientists, engineers and technologists. It does a high percentage of original design work, enabling it to license others—including competitors—to use its patents. It regularly accepts work on a crash-programme schedule. In addition to supplying equipment to Canadian and U.K. forces, it has been successful in supplying navigational equipment to the U.S. Airforce and the Federal Republic of Germany among others.

Unfortunately, all that was readily available to Bob relating to the Honick display were several photographs of an assembled display unit with side covers removed and schematic diagrams

illustrating proposed map assemblage layout. At a planning meeting it was concluded that ComDev must be behind the competition and in addition handicapped by the absence of Honick's working drawings. Some means had to be found to catch up. The strategy decided on was to offer the R.A.F. a different map display with man unique and added features.

The next few weeks were spent evaluating possible improvements based on several years experience on other navigational systems. During the investigation it was determined that the large size of the Honick display could not be reduced simply by utilizing North Amercian components. The ComDev moving map display would, therefore, bear little resemblance to Honick's and in consequence, little help could be expected from Farnborough. It was recognized that the new approach would result in a much more intensive programme than originally planned. To remain competitive the original time schedule for completion had to remain in force regardless of the expansion of the programme. The new philosophy was presented to the R.A.F. and several weeks elapsed before they accepted it. To meet the planned schedule the project was kept active and forging ahead.

The purpose of the instrument was to provide a navigator with his aircraft's present position against the background of a topographic map. Such a facility was not new and several such devices were in existence. The limitations of these devices were small area coverage, lack of map detail and large equipment sizes.

Honick of Farnborough and Gillfillan of California had constructed displays using a filmstrip as the basic storehouse for map data. These displays were not suitable for two-seater high performance aircraft. Honick's was too large, Gillfillan's was too dimly lit and both displays required the navigator to participate when changing from one film frame to another. Additionally, both displays were merely repeaters of positional data generated by separate navigational computers.

Computing Devices planned to make up for the short-comings in the new display by making a display with relatively small display size, high level of screen brightness, completely automatic map movement, and inclusion of a small flexible navigational computer.

The display was to be obtained by projecting miniature topographic maps set down on a 35 m/m colour film through an enlarging lens system onto a five inch diameter viewing screen.

Because there is much to do in the cockpit of a fast low-flying aeroplane, the performance logistics requires navigational aids to perform virtually without attention. Most air-strikes are pre-planned and the route to target is made up of a series of legs. Each leg termination point is selected for easy recognition. To accommodate this, ComDev's display was to include a destination selector. Each one of the selector positions would correspond to the latitude and longitude of a termination point. This facility was to be available to and from the target. Turning of the selector was to cause the display pointer to orientate to the termination course and the range counter was to show the distance to termination point. To each termination the pilot would turn the craft until the course pointer was

at twelve o'clock and run the range counter down to zero.

The proposed map display was to provide a continuous display of the terrain between termination points. The method for referencing the display involved flying over an identifiable earth feature and the earth feature on the display could be adjusted into the centre circle thereby providing correction.

It is not unusual to find that inclement weather conditions or tactical events prevent usage of a pre-selected landing location. The display, therefore, was to include a means of permitting the navigator to use the map to select an alternate landing site of his choice. Range and course-to-steer to the selected site would be chosen and shown by the display. The same feature could be used in support of air strikes directed from the ground.

On the closing legs of a strike it is expected that violent evasive action on the part of the aircraft may be necessary. Under these circumstances it is desirable to provide the navigator with the means of determining whether the target will be reached. The incorporation of a 'look ahead' feature would cause the intended target to advance to the display centre circle if the pilot was on course. The same feature could also be used to look for mountain ranges or other obstacles long before they came within visible range.

As Bob Vago said, "It is not surprising that much original system activity was to come out of these operational requirements and that several patents were secured."

A schematic diagram for the overall system was used to establish the basic design philosophy. From this, component requirements and inter-relationships were established.

With the exception of servo-loops, most of the parameters shown on the schematic were established by theoretical analyses followed by breadboarding. In the case of servo-loops, it was company experience that performance could only be verified with final hardware. Breadboarding was not, therefore, undertaken.

Draftsmen were brought in to lay out the components and to provide the necessary supporting structure. At ComDev engineering approval of all drawings, layouts and detail drawings was a requirement before data is released to the workshops.

"The importance of drafting to the conceptual engineer cannot be overemphasized," commented Bob. "The necessary interface with the draftsman often provides the engineer with frustration. It has been common in recent years to remove the conceptual engineer from design detail carried out on the drawing board. In consequence, fine detail upon which the success of any project depends is left to a draftsman who is not always sufficiently skilled in engineering matters. The original concepts, therefore, undergo distortion, and in some instances, inadequacy in detailing. It is hoped that this state of affairs will pass with time. It will indeed be a great day for the conceptual engineer when computer-assisted design is an every day occurrence."

At the time the programme was undertaken, ComDev was changing from a project to a functional organization, and there was a great volume of development work that had to be carried out. In consequence, Bob Vago was left largely on his

own to fend with the project. While drafting assistance was available, little direct assistance of any consequence was available for several months. Much assistance was sought outside the company without which progress would have been much slower.

The first prototype was shipped to England in April 1963.

THE DEVELOPMENT OF TOPOGRAPHICAL NAVIGATION DISPLAYS IN THE UNITED KINGDOM

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Instruments and Electrical Engineering Department
Royal Aircraft Establishment, Farnborough

FIRST DEVELOPMENTS

The development of pictorial navigation displays in which aircraft ground position and track are superimposed on the projected image of a topographical map was initiated at the Royal Aircraft Establishment, Farnborough, in August 1959. Operational flight experience, dating from 1952, with roller strip maps driven from Doppler groundspeed data in an "along and across" planned track mode had demonstrated the advantages of a continuous, automatic plot of ground position. Tactical limitations were the necessity for preparing the full-scale map strip before a flight and the inflexibility of the plan which provided little freedom for changes of flight plan or diversions.

Optical projection displays were developed with the aim of storing a complete operational theater in one loading by microfilming maps in color, the film being driven in geographical coordinates. Tactical freedom of operation over the whole area stored in the instrument was therefore possible. Projection of a moving image on a circular screen surrounded by a degrees scale and the superposition of a central symbol representing the aircraft, together with a diametral arrow rotating in accordance with aircraft track, produced an illusion of greater realism than the roller map and also permitted extrapolation of the present position by laying track ahead over the topographical detail. Anticipation of features ahead and the ability to make good any desired feature shown within the field of the display was therefore simple.

An original experimental model built in 1959 is illustrated in Figures 1 and 2. The first concept was to store the microtransparencies on a transparent cylindrical drum driven by resolved groundspeed applied as axial rotation and axial translation.

The diameter of the cylinder was large enough (6 1/2") to accommodate the area required and the curvature sufficiently small over the area projected to be accepted by the optical projection system.

This instrument was flight tested in 1960 with encouraging results. The drum store has the advantages of providing a stable support for the film, preserving focus, and permitting precise traction. The map detail is also arranged with areas in their correct juxtaposition.

Storage capacity, however, is limited by the cylindrical area and the moving parts are bulky. The principle was therefore abandoned in favor of area storage on perforated, 35mm motion picture film stored on spools using the perforations for traction in one ordinate.

Engineered models of the second type were designed in 1960 and became available in 1961. The instrument is illustrated in Figures 3 and 4. This instrument had facilities for presenting the image either North stabilized or Track stabilized and was fitted with a dual lens turret providing an optical scale change from 1:500,000 to 1:1,000,000. Two lamps were provided with a changeover facility together with stepwise dimming. Using 100-watt lamps and a plastic Fresnel lens in front of the translucent screen as a field brightener, an image brightness of 700-1000 foot-lamberts was obtainable.

These instruments were operated from groundspeed derived from Doppler and track derived from a combination of Doppler drift and gyromagnetic compass heading, groundspeed being resolved by analogue computing into Northings and Eastings. Miniature D.C.

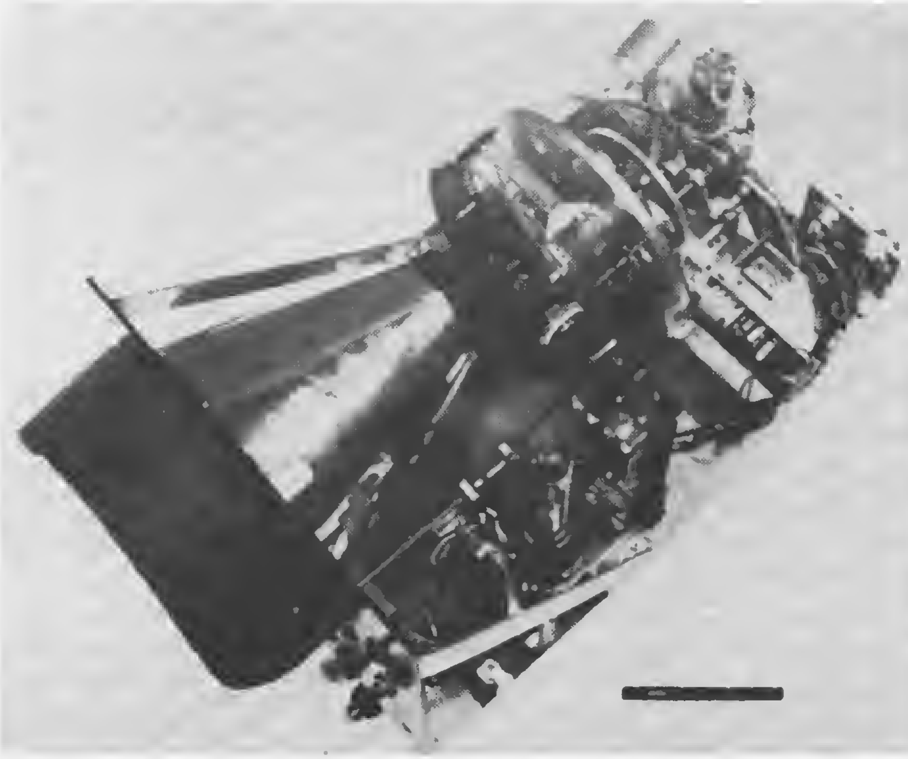

Figure A-1. Topographical Navigation Display No. 1. 1959. Interior.

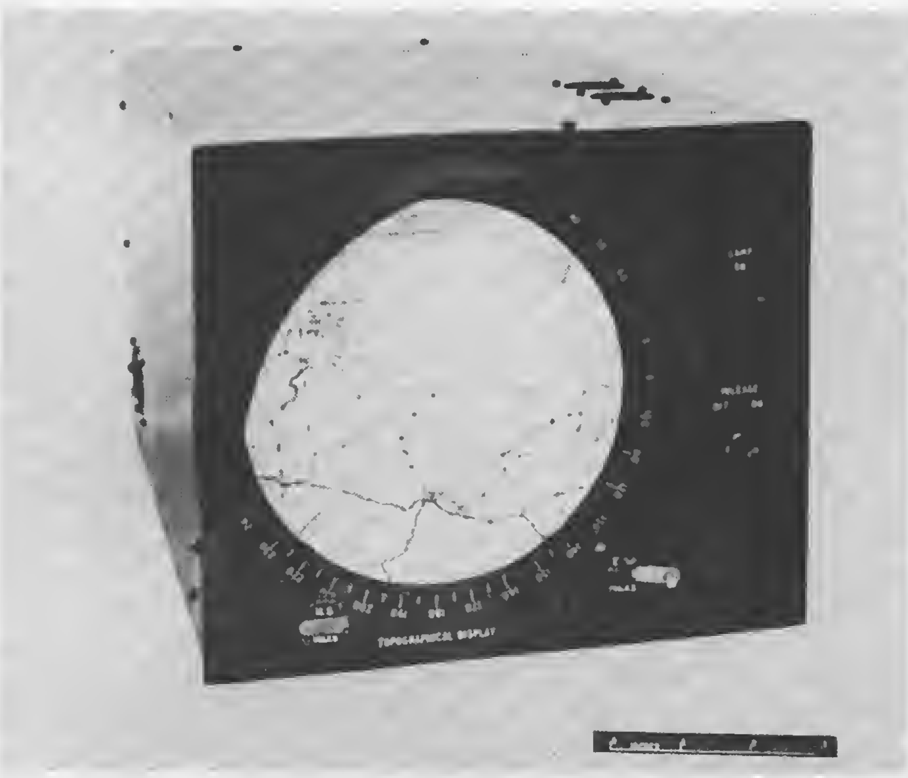

Figure A-2. Topographical Navigation Display No. 1. 1959. Exterior.

EXHIBIT A-1

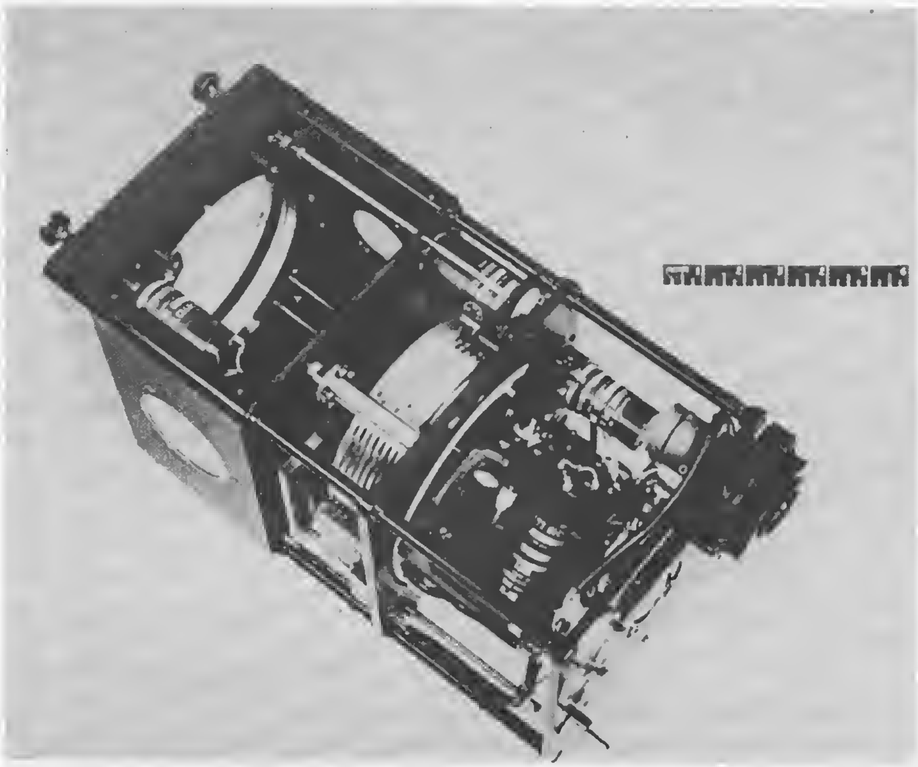

Figure A-3. Topographical Display No. 2. 1960. Interior.

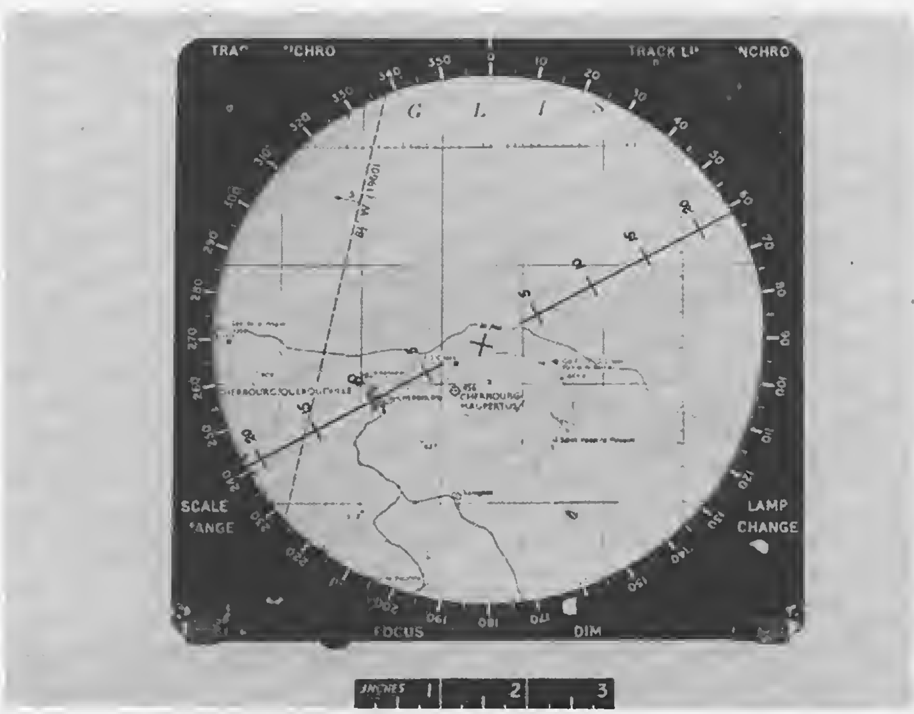

Figure A-4. Topographical Display No. 2. 1960. Exterior.

EXHIBIT A-1

stepping motors were used for the film traction system from the outset, the resolution (144 steps per nautical mile) being sufficiently high to give the appearance of smooth motion. These displays were driven as simple, open-loop devices, but the adaptability of step motors to operation from digital outputs was appreciated.

The storage capability on film strip is shown in Figure 5. Using a reduction factor of 19x, a published sheet of topographical map covering 2° of latitude can be accommodated on one 24mm x 36mm standard double frame on 35mm film. The area illustrated, covering 20° Lat. (1200 nautical miles) NS by approximately 53° Long. EW (approximately 2400 nm at 40N), is stored on 140 frames corresponding to 17 1/2 feet of film.

The maps used were standard RAF Topographical charts on Lambert's conformal projection.

Figure 5 illustrates the technique adopted to mechanize the frame change NS and to minimize the convergency effect of driving conical-projection maps in Cartesian coordinates. Successive frames were arranged with their central meridians vertical and parallel to one another. The published sheets were re-edited to provide an overlap EW and to arrange a consistent separation of the central meridians, so that the distance along the film required for a frame shift NS was a constant. A semi-automatic, fast-slewing facility was provided for this purpose.

Display development was initially aimed at a two-cockpit installation in which parallel displays were provided for both the pilot and the navigator, control of both being centered with the navigator. Some manual monitoring of the displays was therefore tolerable and complete automation of frame changing was not provided at this stage. Facilities for correction of the display to a fix were provided, the associated analogue computer being provided with a memory store of resolved mileage which could be discharged into the display after correction.

FLIGHT EXPERIENCE

Displays of the type described have been extensively evaluated in flight at high and low level both as a navigator aid and as a pilot aid. Similar models have been produced in quantity and have been used operationally.

Test flying, centered at the Royal Aircraft Establishment from 1961, confirmed the notable increase in information content of the display from

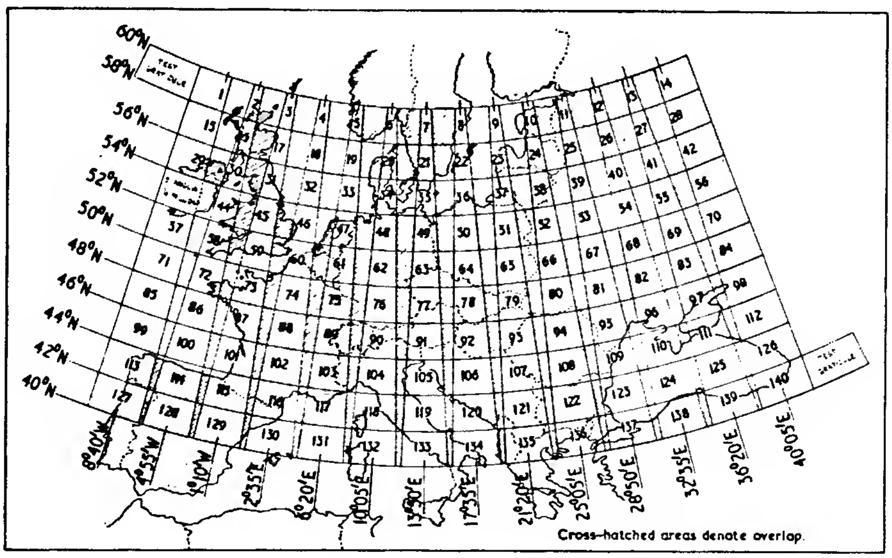

Figure A-5. Map Storage Capacity of Topographical Display No. 2. 140 frames.

data sources hitherto used only to present latitude and longitude values.

The elimination of plotting, the reduction in work load and the continuous availability of a present position indication without time lag in a readily interpretable form in relation to all surrounding geographical features were all substantiated.

The ability to anticipate and to make good desired points was generally appreciated. Scale changing as a means of looking farther ahead proved to be a valuable facility, and at lower levels, the presence of hypsometric tints was favored.

Except at low level (250-500 ft), the standard 1:500,000 topographical charts employed were reasonably satisfactory for general navigation. At low level and in terminal areas, a larger scale such as 1:250,000 was preferred.

Both pilots and navigators preferred a North-stabilized presentation at heights above about 2,500 feet, but for pilot use at low level the preference for track-stabilized presentation was unanimous.

A separate, low-level trial was mounted for evaluation as a pilot aid in the front seat of a Canberra PR-7 aircraft. Dashboard installation was not practicable, but the display was mounted to the right of the pilot and facing upward as shown in Figure 6. The pilot was not required to adjust the instrument, which was monitored by a navigator in the rear. Experience was obtained in the height band 250-500 ft in this aircraft at speeds of up to 450 knots. Preliminary simulator tests had indicated that it was possible to interpret the display under these conditions, the time interval between the pilot being asked his position from the display and his reply being approximately 3 seconds.

This aircraft was flown by nine pilots, all of whom had low-level experience and three of whom were operational photographic reconnaissance unit pilots. There was a unanimous finding that the display could be usefully interpreted under these conditions. To quote one pilot, "The pilot could navigate with an accuracy which at low level could only be improved on when flying carefully preplanned routes over easily identifiable features. The ability, on sortie, to fly for an hour and twenty minutes over Germany (the pilot's first visit to Germany) at low level without any doubt about one's position to within one or two miles (and with a much less error after seeing landmarks), and being able to explore and divert in any direction at will, shows that there is great potential for this equipment in the role of a pilot navigation aid for high-speed flying."

The property of anticipation, operating in a track-stabilized mode, proved to be the most valuable feature of the display in the low-level trials. The mode of operation was generally to look ahead up the track line on the display for some feature, preferably of an across track character, its distance on the display being estimated by the graduations on the track line. The pilot, knowing his approximate groundspeed, would then watch for this feature approaching and would check as he passed over it.

It was however in the low-level case that the characteristics of the normal topographical maps used were most criticized. Many of the pilots indicated a requirement for "special" maps without being able to define precisely what they wanted beyond the fact that a larger scale than 1:500,000, such as 1:250,000, was desirable.

It was suggested that the low-level air map fulfills a different function from the traditional topographical map, which appears to be aimed at being as comprehensive a plan of terrestrial features as possible within the format. This generally presents far too much information in a given area for high-speed, low-level interpretation, and this becomes worse as the scale increases. A high degree of selectivity should be exercised in the preparation of low-level air maps, which should, it is suggested, aim only at the inclusion of those recognition features which are likely to be of value to the user at the height and speed range at which he is flying. Such features could, moreover, be encoded in a variable manner according to their ease of recognition. For example, railways are normally marked on topographical charts in a bold manner from which the user might suppose that they were always readily visible, except for tunnels. There are, nevertheless, many stretches where railways are not readily visible on account of shallow cuttings or

trees. It would be possible to vary the intensity of the encoding symbol on the map to indicate the ease of recognition. The preparation of low-level maps on this principle requires a knowledge of the appearance of the terrain as seen by the low-level pilot, rather than a surface survey.

Separate flight appraisal by RAF Bomber Command Development Unit throughout 1961 as a navigator aid in bomber aircraft established the reliability and value of the presentation in this role. (Terminal areas at 1:250,000 were interpolated in the 1:500,000 cover provided with the approach and holding patterns marked on the maps.) The display was installed adjacent to a PPI radar display and was found to be valuable as a radar comparator in facilitating the interpretation of the radar display. From side-by-side comparison of the two displays, optical combination and superposition of both at compatible scales is a logical development.

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ECL 166B

MOVING MAP DISPLAY (B)

The result of Bob Vago's effort at Computing Devices of Canada was a novel aircraft navigating instrument that displays a map of the region flown over, and shows the aircraft location on the map. (Exhibit I & II).

The display is on a 5 inch screen, showing a map in colour. Present position is indicated by a small circle in the centre. The circle stays fixed and the map moves under it. The map is on a single strip of 35 mm colour film, moved automatically and continuously sideways and forward in accordance with the actual path of the aircraft. Sideways movement of the filmstrip is avoided by having it automatically wind to the next matching section and then continue to traverse.

Prepared by Professor G. Kardos with support by the National Science Foundation with cooperation and information from Computing Devices of Canada Ltd.

MOVING MAP DISPLAY (B)
COMPUTING DEVICES OF CANADA LTD.

The details of the design as abstracted from the patent application are given in Appendix A.

The heart of the apparatus is a filmstrip having a number of frames in abutted end to end relationships spaced as shown in Exhibit B-3. The filmstrip is contained in a film cassette. Each frame is a transparency representing a part of a map area. A portion of a frame is positioned in the projector light path projecting an image on the screen.

The main frame of the apparatus has a light projector at one end (Exhibit II) and a display screen at the other end. The light passes through the aperture in the cassette and is focused by means of a lens system onto the screen.

The film positioning is achieved by servo-mechanisms which rotate the turntable, translate the cassette, and wind the filmstrip.

The film cassette with its carriage servo components is mounted on a turntable. The turntable orients the display. The turntable is rotated by a servomotor mounted on the housing. When track orientation is called for, the table is oriented so that the aircraft heading corresponds to the fixed track line on the screen.

The film cassette is mounted on a carriage. The carriage is positioned by a motor-driven lead screw to provide north-south display movement across the width of the film. North-south position feedback is provided through a potentiometer attached to the lead screw.

The film is mounted on spools in the cassette. The spools are attached to tensioning devices. The tension devices are connected to produce a constant tension on the film. A sprocket engaging the film drives the film back and forth against the spring tension to produce the required east-west display movement. A potentiometer connected to the sprocket drive provides east-west position feedback.

The housing contains two light sources which can be interchanged in case of failure during flight. Two projecting lens systems are included so that the display can be presented at two magnifications: 1:500,000 and 1:2,000,000.

The apparatus includes a means for receiving a signal representing earth miles travelled and translating this to map displacement. This device resolves the direction and distance travelled into map grid east-west and north-south displacement. These signals and aircraft reading are applied to the respective servo drives.

Various auxiliary functions and alternate operational modes are available and are described in Appendix A.

The 35 mm filmstrip became the heart of the instrument. It was not fully appreciated in the beginning that considerable effort would be necessary to obtain a filmstrip of suitable quality. Since the company had little experience in film technology, they tried to meet the requirements by use of an outside vendor.

To start on the filmstrip it was first necessary to evaluate various map

projections for suitability. The Lambert Conformal projection was selected because of its low distortion of earth features regardless of latitude. An evaluation of the projections' properties established that an area roughly 1800 x 1800 nautical miles could be stored on a 35 mm filmstrip 25 feet long and that the standard parallels of latitude should be 36° and 54° North.

The next requirement was to determine the type of film and its drive means. It was thought at first that the most acceptable results would be obtained by driving the film with a pressure roller. Thermal expansion of the film and inaccuracies in the drive produced errors of an unacceptable level. A film sprocket drive was chosen thus enabling use of standard sprocketed film.

Copying U.S.A.F. pilotage charts onto the 35 mm film presented a formidable number of problems; corrections for Lambert scale factor between earth and chart, for chart shrinkage, for scale factor and for variation in film strip sprocket pitch. Provisions also had to be made for north-south map overlap, for enlarged markings, for high advance and for abutment accuracies.

The commercial microfilm facility used in the early phases of the project soon proved unable or unwilling to cope with the requirements.

In consequence, it became necessary for the company to purchase a microfilm facility. Before the microfilm camera could be used it was necessary to strip out the existing mechanism and replace it with a re-designed one which met the high standards required.

Next it was necessary to select a colour film type, on which would exhibit faithful colours and which would have sufficient resolution to prevent blurring of fine detail on the projection screen.

Several European and North American film types were evaluated. Resolution was determined with the assistance of a colour resolution chart provided by the United States Bureau of Standards. This chart was photographed with a high quality microfilm camera and the developed film types were compared under a high power microscope. Colour reproduction was checked by comparison of pilotage charts to full size screen blowups.

Once the film type had been selected, it was necessary to persuade the film vendor to provide the film in the required long lengths.

All servo-loops were analysed theoretically to establish response characteristics and the required component parameters. Servo testing was carried out on the final hardware. Apart from the unexpected behaviour of a critically placed antiblacklash gear all servo loops behaved as predicted.

Optical path analyses were carried out on all optical components excluding the internal elements within the compound lenses. The lenses were proprietary and had to be obtained from France.

When all the optical components were available, a thorough breadboarding programme was instituted to determine screen image resolution, screen brightness against ambient light level, and the effectiveness of heat abstraction techniques over a wide

ambient temperature range. The analysis aimed at a legible display with minimum colour washout in an ambient light level of 4,000 ft. lamberts. Field experiments confirmed that in some applications performance under an ambient light level of 10,000 ft. lamberts was necessary.

The design objective was for quantity production not exceeding two hundred fitments. This number was chosen based on typical production quantities for similar navigation equipment.

Apart from supporting structures, interconnecting linkage, including gear passes, most items were purchased from vendors. Such items included servo amplifiers, synchros, electric motors, gear boxes, transformers, saturable reactors, capacitors, semi-conductors, resistors, projection lamps, lenses, slip rings, brushes and many other small items.

Most vended items were custom built and, therefore, required explicit specification control drawings to be generated by the engineer in order to effect their purchase. ComDev experience showed that certain vendors would over-estimate their capability of meeting the standards required.

It is usual practice on production programmes to divide a requirement between two or more vendors in order to protect the project. In development programmes, limited funds usually inhibit this practice. In addition, only one vendor can be persuaded to cut back his development costs to a reasonable level on the assurance that recovery is almost guaranteed on follow-on production programmes.

"Because development time for some of the more important components often represents a significant portion of the time allowed for the project it can prove fatal if an unsatisfactory component shows up. On this project, this occurred twice and it was most fortunate that a second vendor produced the required components in time. It was annoying to find that the only liability of the vendor under these circumstances was the cost of the component provided" Bob recalled.

Bob Vago felt that "On short development programmes most of the skills required should be housed within the Company. The decision to make or buy should be limited only by this consideration. Such action is prudent even though the company standards may be questionable when compared with an outside vendor."

As ideas formed they were weighed for suitability within the design constraints. If an idea did not measure up it was modified or discarded. "The chosen concept did not evolve from a conscious permutation of known techniques, knowledge or skills, but rather by what is called intuitive thought. We were not conscious of an idea until suddenly it formed in our mind. The thought process appeared random with the time concentration" recalled Bob.

Many of the ideas evolved over a lengthy period of time. In some instances optimization occurred after breadboarding. At no time was any attempt made to employ formal analytical optimization methods.

The operational requirements for presentation of navigational data have developed over the years. Consequently there is little room for the industrial designer. Pilots and navigators are most reactionary to proposals for modifications to

existing navigation presentations. There is, of course, good reason for this attitude. It is important that under the stress of operational combat, interpretation of conventional navigational quantities takes place almost as a matter of reflex.

This attitude was reflected with respect to the map display's track counter. For Bob, his display counter represented a significant advance over the conventional compass ring. Navigators comments regarding this track display were never enthusiastic and often the request for return to the conventional compass ring was heard.

The use of the compass ring would have made the display significantly larger and this was the prime reason Bob didn't use it.

Guidance for human engineering factors in aerospace equipment is set on many programmes by the U.S.A.F. document AFSCM 80-3. It is normal, therefore, in the absence of a special requirement to work to this U.S.A.F. document. The characteristics of colour and contrast of the map representation on the screen was not covered by the referenced document.

Controversy existed regarding desirable contrast in the display. Mr. Honick was of the view that blacks and reds were desirable. With this, clarity of the display was improved, but at the expense of eye fatigue. ComDev chose the soft greens of the U.S.A.F. Pilotage Charts. The contrast was not as good as Honick's reds and blacks, but there was no problem with eye fatigue, and also there was no problem in securing wide territorial coverage.

No ready solution was available and it was generally agreed that no existing topographic chart had the desirable contrast characteristics. In the time available, it would have been out of the question to have had a cartographer create a special series of maps for the display.

A target cost for the development phase was allocated based on reconds of previous programmes of similar complexity.

The only portion of the programme which caused serious cost difficulty was provision of the microfilm copying facility. Fortunately, the cost involved was largely written off by the facilty's ability to meet the required microfilm standards.

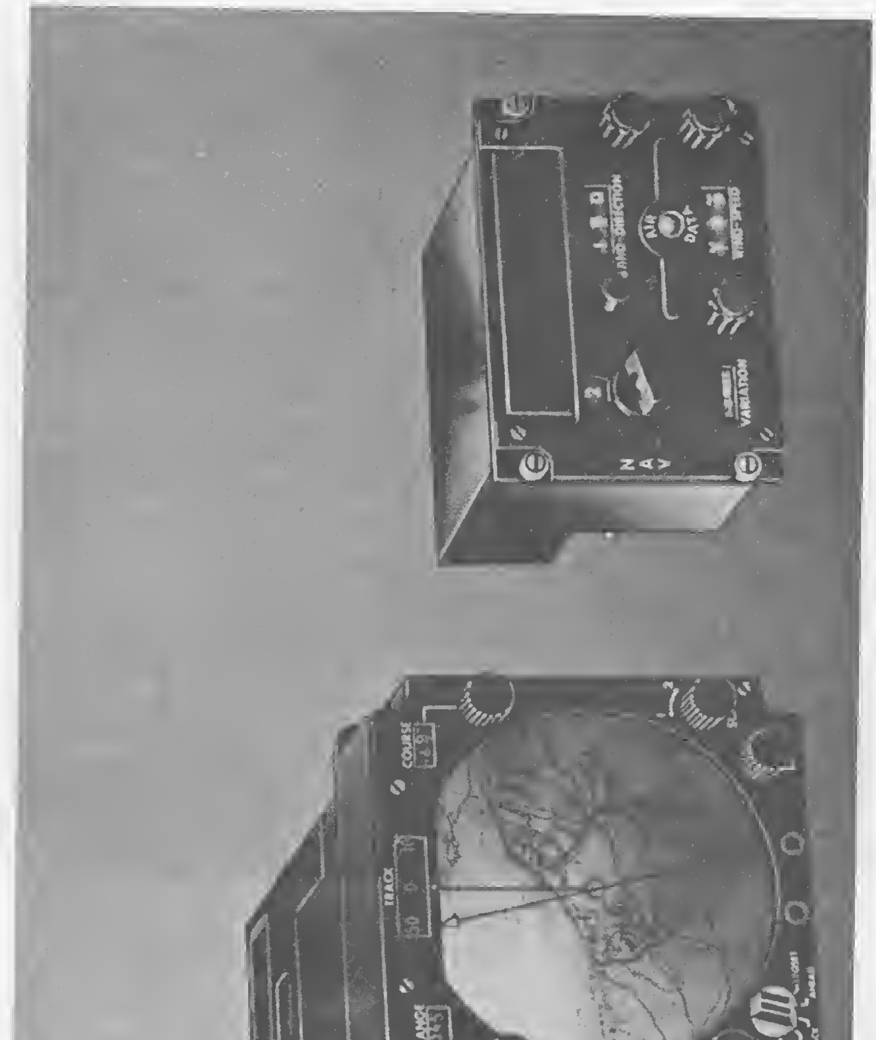


EXHIBIT B-1

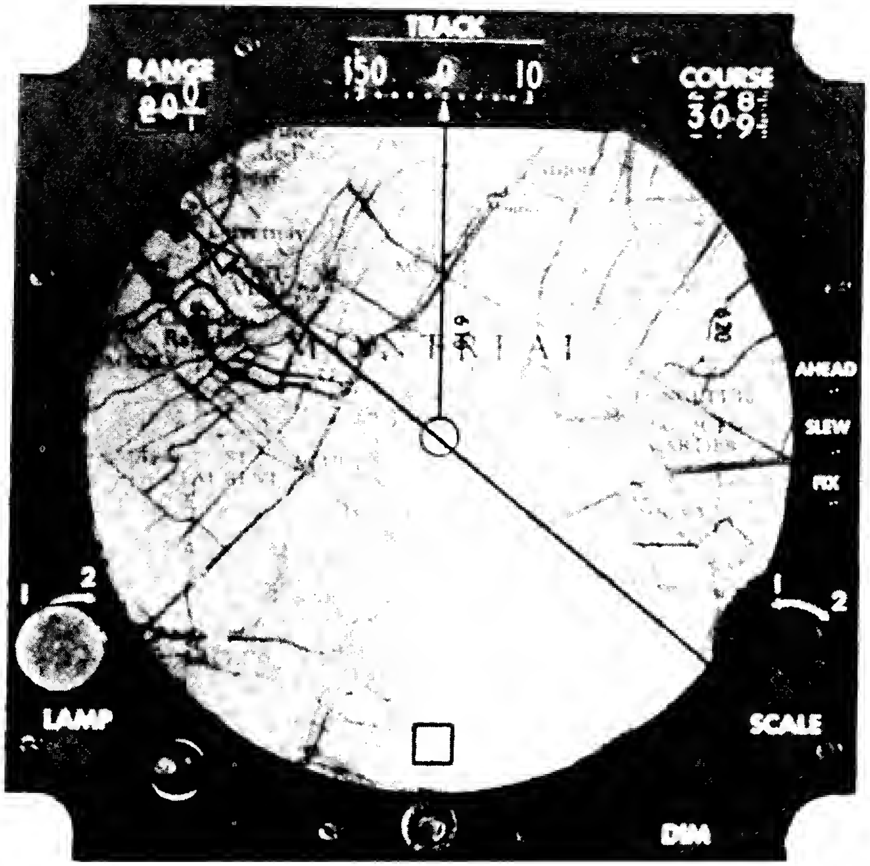


Figure B-1. The Appearance of the Moving Map Display.

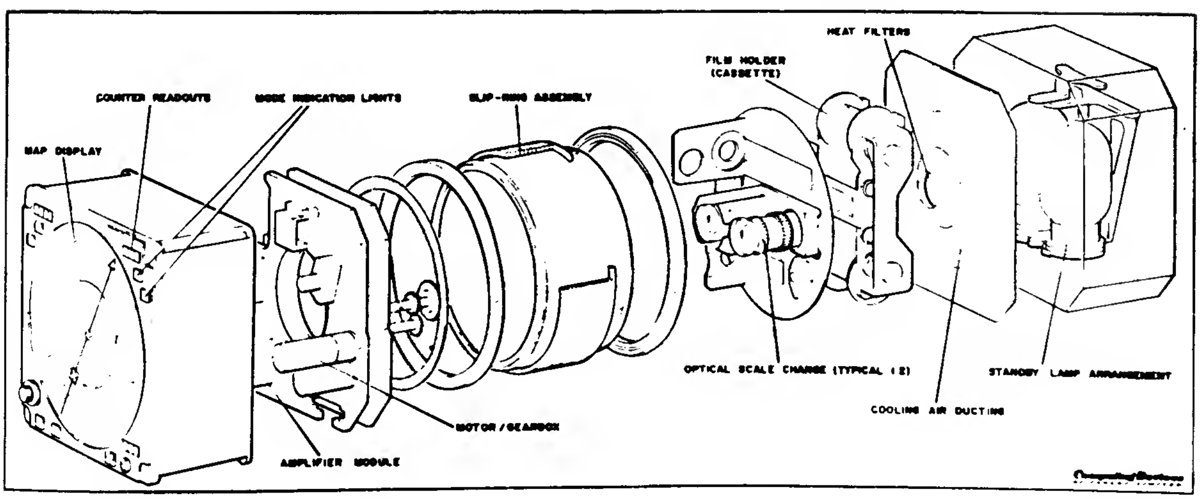


Figure B-2. The Mechanization of the Moving Map Display.

EXHIBIT B-2

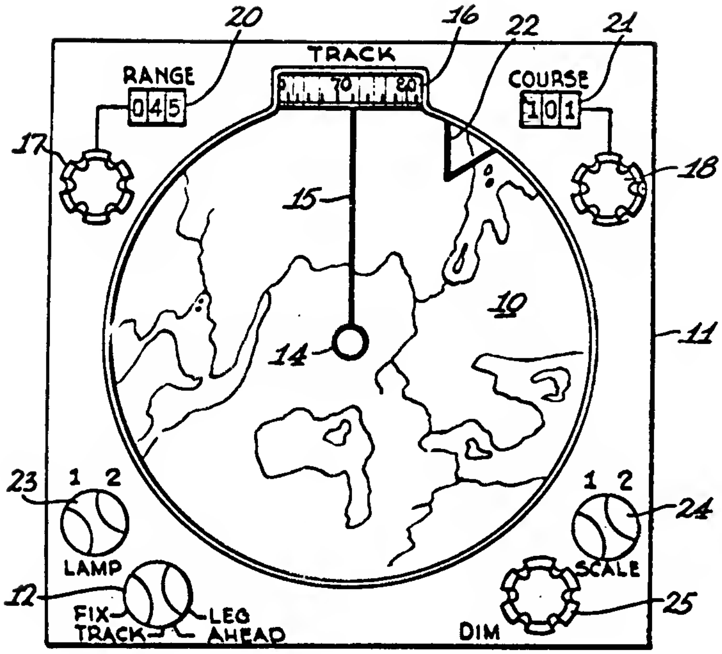


Fig. 1.

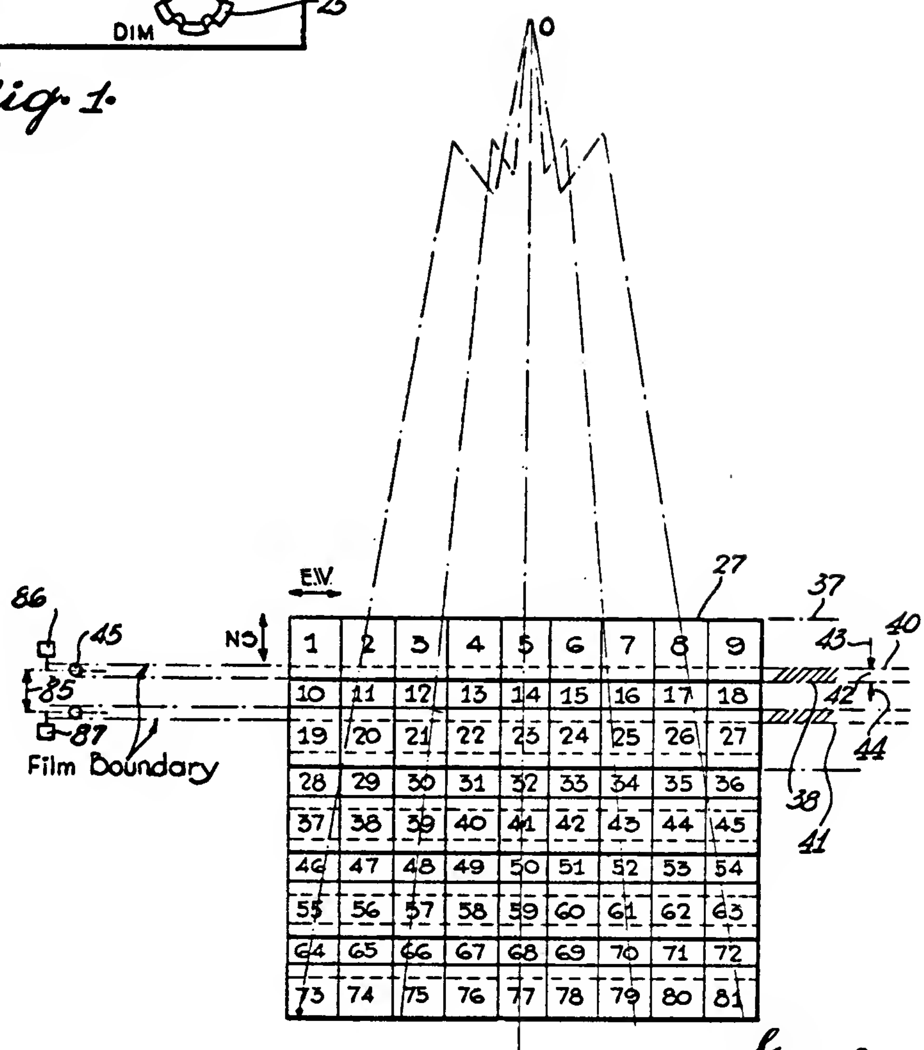


Fig. 3.

EXHIBIT B-3

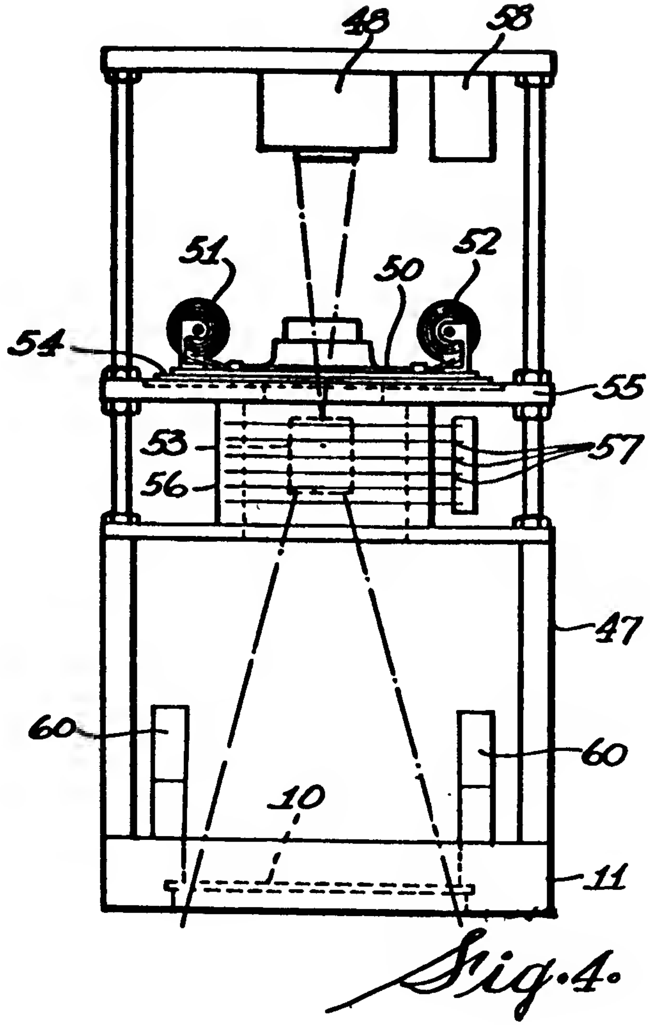


Fig. 4.

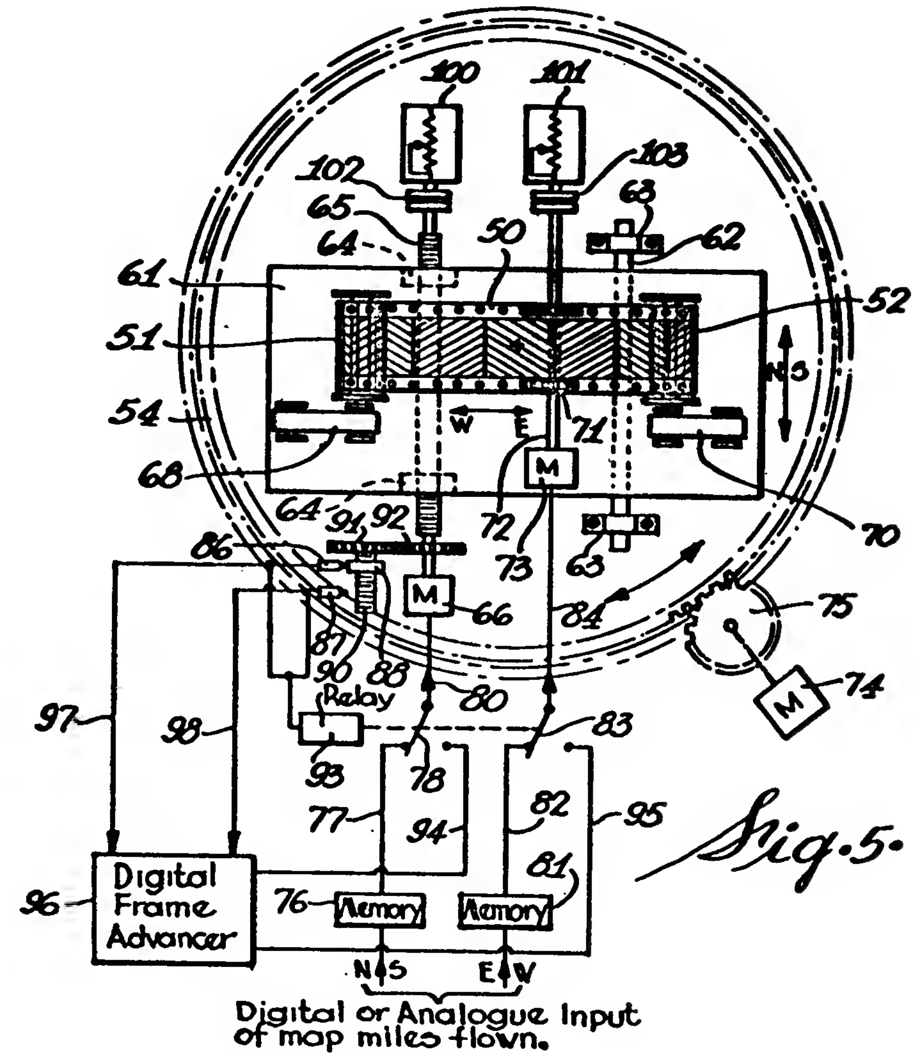


Fig. 5.

EXHIBIT B-3

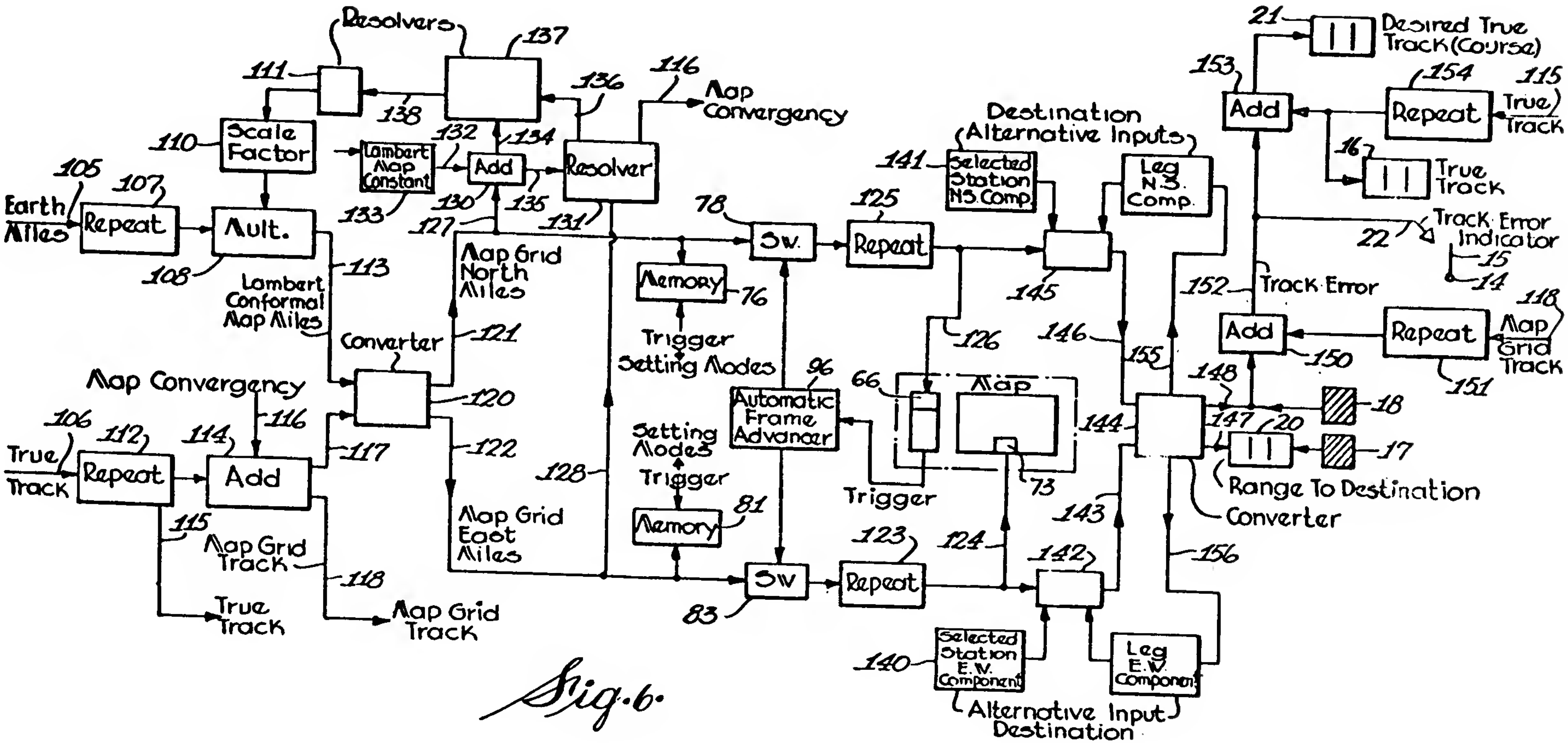


Fig. 6.

EXHIBIT B-3

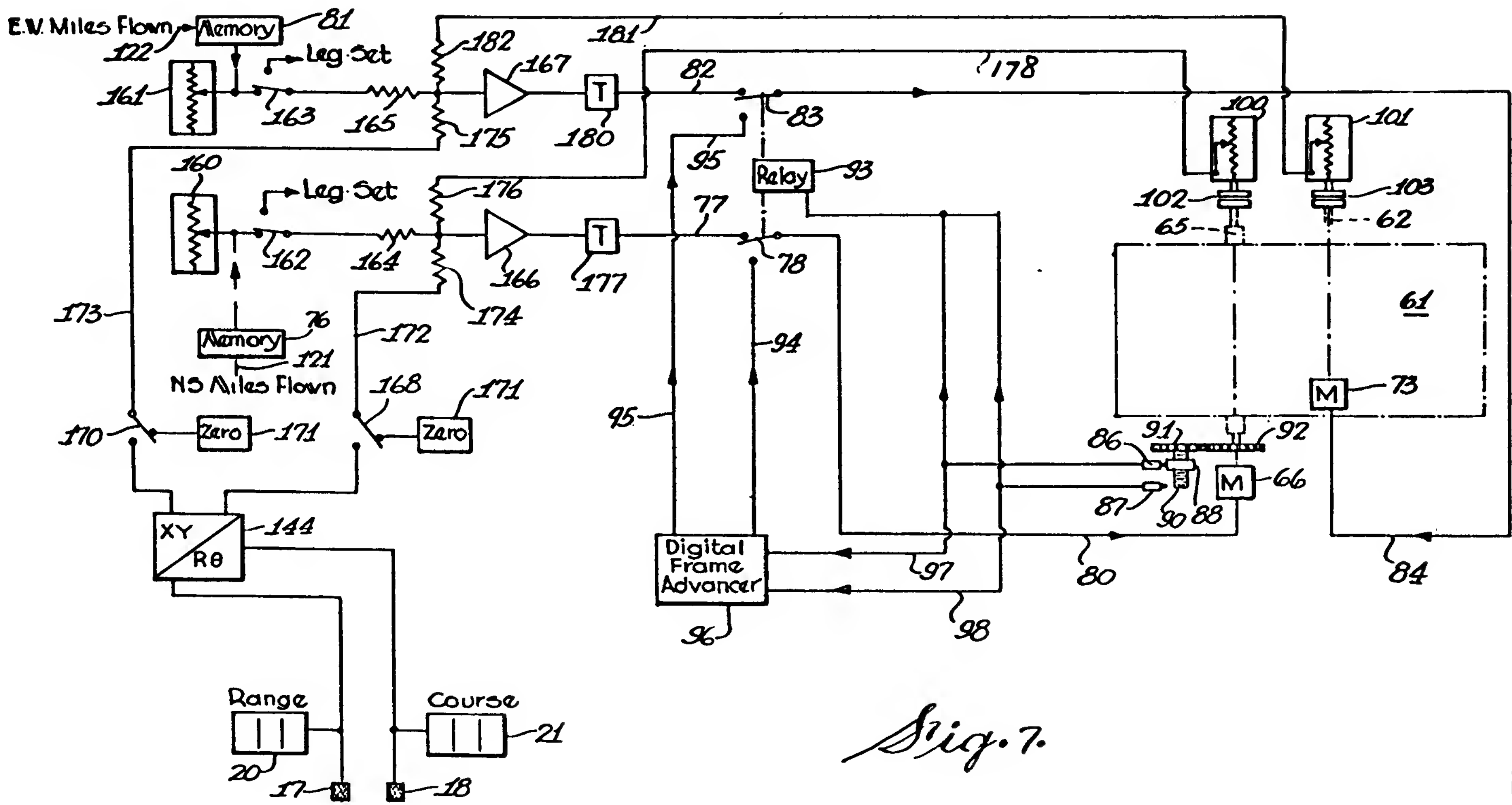


Fig. 7.

EXHIBIT B-3

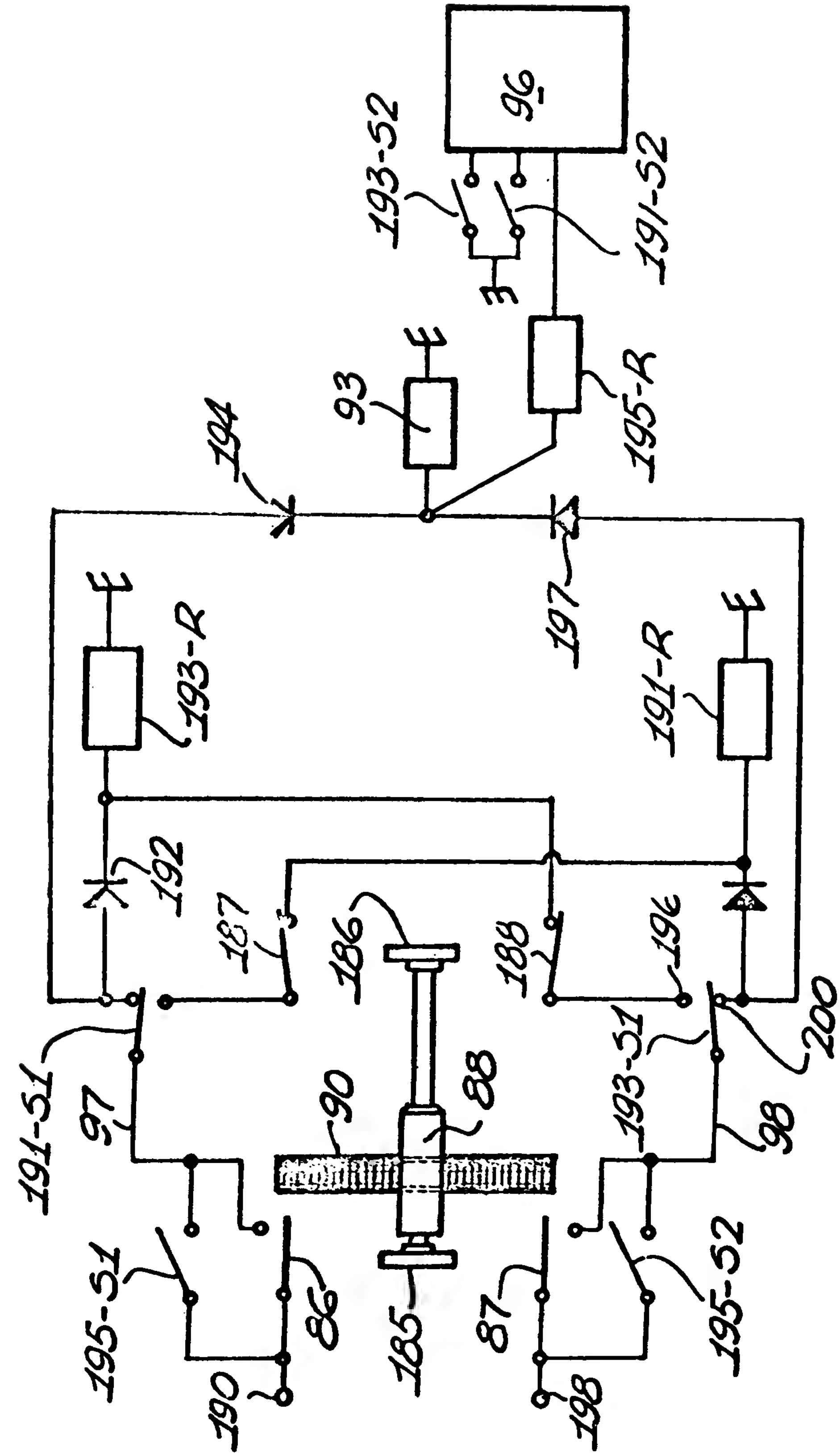


Fig. 8

EXHIBIT B-3

MOVING MAP DISPLAY (B)
APPENDIX – DETAIL DESIGN

This appendix describes the detail operation of the moving map display. The part numbers refer to parts shown in Figures 1, 3, 4, 5, 6, 7, and 8 (Exhibit B-3). The description follows closely that of the patent application.

Briefly, the present invention is for a navigational apparatus for use in a piloted craft and having a display unit comprising a frame, a light projector mounted at one end of the frame, a display screen mounted at the other end of the frame in the projector light path, a turntable mounted to the frame between the projector and the screen having a light passing aperture therethough, drive means mounted to the frame and engaging the turntable for orienting the turntable in a pre-determined orientation, a film transport mounted to the turntable and having back and forth movement in a first direction, a film strip holder carried by the film transport and incuding a film driving sprocket rotatable in a second direction at right angles to the first direction, a first drive mounted to the turntable and connected to the film transport having a film transport driving rate responsive to a component of movement of the craft in a fourth direction at right angles to the third direction, a switch mounted to the turntable and operable upon movement of the film transport in the first direction to a forward and backward limit, respectively, means actuated by the first switch energizing the first drive for a predetermined movement at an accelerated rate, and means actuated by the first switch energizing the second drive for a predetermined movement at an accelerated rate.

The film strip holder preferably holds a strip of film having a plurality of frames in abutting end to end relationship. Each frame is a transparency representing a part of a map area. A portion of a frame is positioned in the projector light path projecting a map image on the screen. The film strip and consequently the map image are moved by the first and second drives in accordance with movement of the craft to show craft position.

The apparatus also includes the means for receiving a signal representing map miles travelled, means receiving a signal representing true track and deriving therefrom a signal representing map grid track, means converting the signals representing map miles and map grid track into signals representing north-south and east-west components of craft movement in map miles, and means applying these latter signals to the first and second drives for positioning the film strip.

In a preferred embodiment, a destination position may be set into the apparatus. Two signals are resolved from the destination position representing north-south and east-west components of craft position to energize the first and second drives causing the film strip to move to project on the screen an image showing a map representation of the desired track to destination.

Figure 1 shows the display unit as it would be seen by the operator. A screen (10) occupies the centre portion of a front panel (11) of the display unit. An image of a portion of a topographic map is projected onto the screen from a film strip. The apparatus has four operational modes which may be selected by the mode knob (12) the normal mode is the "track" mode. When operating in the "track" mode, a

small fixed circle (14) on the screen represents the present position of the aircraft, and a fixed line (15) represents aircraft track. As the aircraft moves over the terrain the map image moves correspondingly along track line past the present position circle. The frames in the film strip change automatically when required. The track being made is shown on track indicator scale (16). Thus, the operator always has before him a map display showing aircraft present position with aircraft track indicated above.

Another mode of operation is the "leg" mode. When this mode is selected, a desired leg of a flight can be established to a destination at the end of the leg. The destination position may be set in by means of a separate push-button unit, or it may be set in using a range knob (17) and a course knob (18). The range or distance to the leg destination is shown on range counter (20), and the desired course or track to the destination is shown on counter (21). When this destination has been set in, the knob (12) can be turned to place the apparatus once more in the "track" mode. Then the range and course continue to show the remaining distance and course or bearing to the destination. In addition, once a destination has been set in and the apparatus is in the "track" mode, an indicator (22) indicates the desired track to the destination. Displacement of the indicator from track line (15) shows track error.

Another mode of operation that can be selected by knob (12) is in the "look ahead" mode. When this mode is selected, and when a destination has previously been set into the apparatus, the map display automatically advances at an accelerated rate along the desired track to the destination. This provides the operator with an opportunity to look at the terrain, shown by the map, over which the desired track lies. If desired, knobs (17) and (18) can be rotated to slew the projected map image around to look at any particular part.

A "fix" mode may be selected by the knob (12). This mode is provided to correct positional errors in the display. If a fix is obtained and the position of the fix does not correspond to the position shown on the map display by the present position circle (14), then the "fix" mode is selected and knobs (17) and (18) operated to position the display in accordance with the position of the fix. The apparatus is then returned to its "track" mode, the input signals representing the aircraft movement are fed into a memory and stored. When the "track" mode is again selected, the stored signals are taken from the memory to move the projected map image so that the display will again show the position of the aircraft.

The scale control knob (24) selects one of two optical magnifications for the projector. Thus, the magnification can be changed to meet different requirements. The scale of 1:500,000 provides a viewing radius of about 17 nautical miles on screen (10) and the 1:1,000,000 scale provides a viewing radius of about 34 nautical miles.

It will be noted that the display, as described, has the aircraft track towards the upper part of the display on Figure 1. This is normally the most convenient display for the pilot. Provision is also made to orient the map display with North represented by the upper part of the display as seen in Figure 1. A spring loaded switch is incorporated in knob (18) for changing the orientation.

The apparatus could be readily adapted for use with various map projections. It was, however, preferred to use a

Lambert conformal conic projection. Such projections are well known.

FILM LAYOUT

Referring to Figure 3, there is shown a schematic view of the layout of the frames representing portions of the map area of interest. The map is divided into a series of smaller parts designated by the numbers (1) to (31). The parts are arranged in rows and columns. Each of the designated 81 areas represents a part of a topographic map photographed as one frame on a film strip. The frames are positioned so that the frames (1-9) represent a continuous strip, frames (10-18) represent a continuous strip, and so on, and there is no overlap or separation on the film strip between frames.

Because of the interruption when a frame boundary is reached in the display resulting from NS aircraft movement, it is convenient to have an overlap between areas represented by adjacent NS frames. This NS overlap is shown in Figure 3. The amount of overlap is chosen so that on any frame it will provide a full display when projected onto the display screen, and will just fill the screen. Thus, when the film strip is being moved to change the projected image from one frame to another representing an adjacent NS map portion, just before and just after the change the same image will be displayed and each image will fill the display without showing the edge of the frame.

DETAIL OPERATION

In Figure 4 there is shown a general layout of the main parts of the apparatus. The light system (48) directs light through a portion of a strip of film (50) extending between spools (51) and (52). These are on a turntable (54) rotatably mounted in a bracket (55) on frame (47). A slip ring assembly (56) is mounted to move with the turntable. A set of brushes (57) mounted to frame engage the slip rings. A blower (58) is provided for cooling the projection system and servo mechanisms.

The turntable (54) is shown from the top in Figure 5 with its associated parts. Mounted to the turntable (54) is a film transport (61) which moves back and forth in the direction marked NS. Towards one end of transport (61) a shaft (62) is fixed to the transport, driven by shaft (65) which in turn is driven by a reversible motor (66). When motor (66) is energized it moves the film transport in the direction marked NS. The shaft (62) supports and guides the transport to ensure only movement in the NS direction.

The spools (51) and (52) are mounted to the film transport (61) with the film (50) extending between the spools. Tensioning devices (68) and (70) are mounted to film transport and connected to the spools. The tensioning devices are designed to keep a substantially constant tension on the film strip regardless of the amount of film on each spool. A sprocket (71) engages the edge holes in film strip (5). A reversible motor (73) is connected to the sprocket shaft (72) for driving the film from one spool to the other in an EW direction.

A turntable drive motor (74) is provided for driving the turntable (54). The orientation of the turntable in Figure 5 is in a NS direction. The motor (74) is driven in response to a signal representing true track.

Light from the projector passes

through a portion of film strip (5) to provide a map display image. As the aircraft moves the motors (66) and (73) are driven to provide movement of the film in accordance with aircraft movement, and the motor (74) is driven to maintain the required orientation of the turntable and the film strip. The transport drive motor receives its control drive signal from a NS input through a NS memory (76). The film drive motor (73) receives its control drive signal from an EW input through an EW memory (81).

When a NS boundary of a frame in the film strip is approached, the film sprocket drive is energized to move the film strip nine frames at an accelerated rate while at the same time the film transport drive is energized to move the film transport to its opposite side at an accelerated rate. This action is initiated by two micro switches (86) and (87) mounted to the turntable. Thus switches (86) and (87) define limits of movement of the film transport.

Referring now to Figure 5, the micro switches (86) and (87) are shown mounted to the turntable (54). The micro switches (86) and (87) are actuated by a travelling nut (88) which is on a threaded shaft (90). As shaft (90) rotates, the nut (88) is moved along it. The shaft (90) has a gear (91) meshing with gear (92) mounted on shaft (65) driven by motor (66). Thus, the position of the travelling nut (88) always has a direct relationship with the position of the film transport.

When the film transport has reached a position that is its limit of movement north, the switch (86) is actuated by nut (88). A relay (93) is operated to move switches (78) and (83). When the switches (78) and (83) are in this position, the signals representing NS and EW map miles are stored in the memories (76) and (81). At the same time, micro switch (86) initiates the operation of a digital frame advancer (96). The digital frame advancer (96) comprises a pulse generator that provides a discrete predetermined number of pulses to motors (66) and (73). These pulses drive the motors at a substantially faster rate than they are normally driven and they drive them by an exact predetermined amount. Thus, the motor (66) moves the film carriage to its opposite limit, and the motor (73) moves film (50) by exactly nine frames. When the required number of pulses have been applied to the drives the relay (93) operates to return switches (78) and (83) to their normal position. The memories (76) and (81) then feed out the signals stored to bring the position of the film strip up to date.

It is desirable in practice to include means for preventing random operation of the frame advancer (96) during unusual operational manoeuvres. For example, if the aircraft should fly into the region represented by a boundary between two adjacent map strips, say the boundary between frames (1) and (10), and should then turn and fly in an EW direction parallel to this boundary, the apparatus should provide the correct display. As another example, if the aircraft should fly in a NS direction to a boundary and initiate a frame change and should then immediately reverse its direction, the apparatus should recognize this and provide the frame for the correct display. Figure 8 shows a means for preventing random operation under such unusual manoeuvres. To aid in identifying the relays with the switches they control, they are given the same designation number-the relay coil being

followed by the letter R and the switch being followed by the letter S.

The travelling nut (88) has switch operating arms (185) and (186), which are shown in the drawing as extended from the nut to indicate engagement of switches (86) and (87) on one side and switches (187) and (188) on the other side with movement of the nut (88). With the display at a NS boundary, the travelling nut is in a position where arm (185) engages switch (86) and closes it.

The closing of switch (86) energizes relay (193-R) moves switch (193-S1) to ground to complete the circuit through the frame advancer. The relay (93) operates switches (78) and (83) as described in connection with Figure 5. The relay (195-R) functions as a locking relay and when energized closes switches (195-S1) and (S2). This serves to maintain a closed circuit between terminal (190) and conductor (97) after nut (83) with arm (1985) moves away from switch (86) during the frame advance.

When switch (86) has just been closed and the circuit has been established as described above, the frame advancer (96) is placed in an operative condition. A short delay, of the order of 250 milliseconds, is built into the frame advancer to ensure that all relays have completed their operation. After this delay, the frame advancer (96) generates pulses to drive motors (66) and (73). As the pulses are generated, the shaft (90) is rotated and nut (88) with arm (185) moves away from switch (86) allowing it to open. The switch (195-S1) is, however, closed and the opening of switch (86) does not affect the circuit. At the moment the frame advance is complete, the travelling nut (88) is positioned with arm (185) just closing switch (87). There is a circuit established from a voltage source at terminal (198) through switch (87) [and also through switch (195-S2)], conductor (98), switch (193-S1), contact (196), switch (188) and relay (193-R) to ground.

When the frame advancer (96) finishes the frame advance it momentarily provides an open circuit and thereby stops the current flow through relay (195-R) and permits switches (195-S1) and (195-S2) to open. The opening of switch (195-S1) stops the flow of current from terminal (190) and de-energizes relay (93). However, there is still a circuit from terminals (198) through switch (87), switch (193-S1), switch (188) and relay (193-R) to ground. Thus, switches (193-S1) and (193-S2) do not move. Before frame advancer (96) is permitted to operate again, the switch (193-S2) must open and then be re-closed.

It will be seen that if the aircraft should turn and fly parallel to a boundary at this time, that is fly in an EW direction, the arm (185) will not move and switch (87) will remain closed. This will keep relay (193-R) energized and switch (193-S2) closed, preventing operation of the frame advancer.

Now if the aircraft reverses its direction during a frame advance period initiated by switch (86), the frame advance will be complete with arm (185) just closing switch (87) and then the movement of the aircraft in the reverse direction will cause the travelling nut (88) to move farther towards switch (87). Switch (188) is set to open with a short over-travel of nut (88) past the position where switch (87) is just closed. When the additional one-half mile has been travelled, the arm (186) opens switch (188). This de-energizes relay (193-R) so that switch (193-S1) moves to contact (200) and at the same time switch

(193-S2) opens. The opening of switch (193-S2) resets the frame advancer (96), and the switching of (193-S1) completes a circuit from terminal (198) through switch (87) to energize relay (191-R), relay (93) and relay (195-R). Thus, a frame advance is initiated through switch (87) in a manner similar to that initiated by switch (86) previously described.

In normal flying, the aircraft would continue on a course across a boundary between adjacent strips. A frame advance would be initiated for example by switch (86) and would be completed with nut (88) positioned to just close switch (87). As the aircraft continued its normal flight, the nut (88) would be moved away from switch (87) permitting it to open. This would de-energize relay (193-R), move switch (193-S1) to its other contact (200) and open switch (193-S2). The circuit is then ready for the next frame advance.

Referring once more to Figure 5, it will be noted that two potentiometers (100) and (101) are connected through clutches (102) and (103) and disengage during the frame advance operation so that the change in frames does not affect the potentiometer record. The manner in which these potentiometers (100) and (101) are used will be described later.

Referring to Figure 6, the two main inputs to the apparatus are indicated at (105) and (106) representing earth miles and true track. The earth miles signal at (105) must be transformed to a signal representing amp miles before it can be used in moving the map display. The earth miles signal at (105) is passed by a repeater (107) to a multiplier (108), where it is multiplied by a scale factor from scale factor unit (110). The scale factor in a conic projection varies with latitude in some manner.

For any given conformal projection used for preparing the film strip, the upper and lower standard parallels are known and are set into the apparatus prior to using it. The map latitude in degrees is derived in the apparatus to a very close approximation from a map miles to degrees converter or resolver (111). Thus, the output from multiplier (108) is a signal representing map miles.

The true track signal at (106) is passed by a repeater (112) to an adder (114). The repeater (112) also supplies a true track signal at (115) to be used in another portion of the apparatus. The adder (114) also receives a signal at (116) representing map convergency C from a source that will be described later. The output signal from adder (114) represents map grid track and is available at (117) and (118).

The signal representing map miles is input to converter (120), and the map grid track is applied on another imput. The converter (120) is a ball resolver or sin cosine resolver, and is designed to convert from terms of measurement by angle and distance to terms of distance in rectangular co-ordinates. The output from converter comprises of a signal representing map grid miles in a NS direction (ΔNS), and a signal representing map grid miles in an EW direction (ΔEW).

The signal ΔEW is applied through switch (83), repeater (123) and to motor (73) to control the sprocket drive to move the film strip longitudinally. The signal ΔNS is applied through switch (78), repeater (125) and to motor (66) to drive the film transport. Memories (76) and (81)

store the ΔNS and ΔEW signals when the switches (78) and (83) are operated for setting or changing frames or whenever the apparatus is not operating in the "track" mode.

Signals are available for driving motors (66) and (73) to position the film strip and accurately depict aircraft present position. When a NS boundary of the film is reached the automatic frame advancer (96) automatically changes frames as described. An automatic and substantially continuous display of present position is provided. The only adjustment required may be to correct the position when necessary.

The signals representing ΔNS and ΔEW map miles are also applied to adder (130) and resolver (131) where they are processed to determine the appropriate scale factor by resolver (137) and (111).

"LEG" MODE OPERATION

Provision is made to set a destination into the apparatus by a separate push button control or by the controls provided on the front panel. X and Y values of any given position may be applied to the appartus by a push button unit indicated in Figure 6 by blocks (140) and (141). Thus adder (142) receives a signal representing EW from repeater (123) and a signal representing the X or EW component of a selected station, and provides a summed output to a converter (144). Similarly, adder (145) receives a signal representing ΔNS from repeater (125) and a signal representing Y or the NS component of a selected station, and provides an output to converter (144). These signals represent the EW and NS component distances in map miles from a reference to the destination, and are converted to a range and bearing. Converter (144) is a double purpose converter which performs xy to Rθ conversion or performs Rθ to xy conversion. The distance part of the output is used to drive a range counter (20) which shows range to destination. The bearing portion of the output is applied to an adder (150). The other input is a map grid track signal obtained from adder (114) through repeater (151). The adder provides a signal which is the difference of two input signals and represents track error. The track error signal is used to position pointer (22) (Figure 1) and is also applied as one input to an adder (153). A true track signal from repeater (112) and repeater (154), is used to drive the true track indicator (16), (Figure 1) and is also applied as a second input to adder (153). The output from adder (153) is the desired true track to destination, and is used to drive counter (21) (Figure 1).

When the apparatus is in the "leg" mode, the range knob (17) and the course knob (18) may be manipulated to set in a desired destination. The knobs (17) and (18) adjust signals applied to converter (144) which then acts as an Rθ to xy converter supplying signals representing NS and EW components of the change. These components are applied to leg component blocks (157) and (158) to alter them to provide the required output signal to adders (145) and (142). The operation is then the same as when selected station components blocks (141) and (140) were used. The "leg" set mode is completely independent of map motion.

MOVING MAP DISPLAY (C)

In the development of the moving map display and its subsequent field trials, Bob Vago ran into several major problem areas.

The first had to do with the film sprocket drive system (71, 72, 73 Figure 5, Exhibit III, Moving Map Display (B)). The original design had the motor driving the sprocket through an antibacklash gear. This gear also drove the feedback potentiometer. The antibacklash gear used was of the spring loaded two-piece type.

During the initial assembly phase, unexpected hunting of the associate servo loop occurred. It was found that since the motor had to drive the film against the film tensioning spring, high torque had to be transmitted by the antibacklash gears. The original backlash springs in the gear were not sufficient to carry the torques. Consequently, the gears distorted and set up vibrations in the feedback loop.

Prepared by Professor G. Kardos with support by the National Science Foundation with cooperation and information from Computing Devices of Canada Ltd.

MOVING MAP DISPLAY (C)
COMPUTING DEVICES OF CANADA LTD.

The fault was corrected by first placing heavier springs in the antibacklash gear. Subsequently fitting a synchro in place of the gear system did away with the problem all together.

A second problem appeared while the equipment was on trial in England. Its presence was masked at first by other faults in electronic sub-assembly. A large standoff error occurred in the aircraft's position indication after automatic film advance. A simple circuit modification involving wire re-routing took care of the fault.

A more serious fault was the failure of an electronic sub-assembly which continued to plague the design for many months. The Automatic Frame Advancer (Item 96, Figure 6, Exhibit III, Moving Map Display (B)), was a digital unit which indicated and recorded the relationship between frames when the edge of the film was reached. This was the only digital unit in an entirely analog system. Because the power requirements were excessive for the digital unit, the circuit was susceptible to unwanted triggering from transient voltages emanating either from relays or associate power supplies.

The heavy involvement of the electronic circuit designer on other high priority programmes prevented this fault from being rectified sooner. The re-occurrence of this fault caused a most unfavourable impression during field trials.

Another problem that continued to plague the project was the north-south cassette drive. A sketch of the system is shown in Figure 1.

The north-south drive motor drives the nut through a gear integral with the nut. This same gear was used to drive the feedback potentiometers. Consequently, the positioning of the film cassette was dependent on the dimensional accuracy of the lead screw and the associate hardware. Any backlash in the system showed up as position error. This fault showed up during shakedown of the system in England. It took an inordinately long time to correct because a suitable machine shop to make a more accurate lead screw was not available at Boscombe Down.

A final problem that came up was brightness of the display. Although the unit was considerably brighter than existing display systems, it still was not considered optimum. The field trials did lead to criticism of insufficient brightness. The limiting factor on brightness was heating of the film. The film, lamp and lens system are shown in Figure 2.

For reliability, two lamps were necessary and could be swung in position as shown. The two magnifications necessary required the use of two lens systems. The geometric relations of all these components with associated cooling made it impossible to increase the brightness of the screen without excessive heating of the film.

The requirement for two magnifications and the resultant two lens system caused considerable argument between Bob Vago and Wing Commander Lambert. Bob questioned the need and utility of the two magnifications. He felt that it added unnecessarily to the complexity of the device. He also was of the opinion that with a single

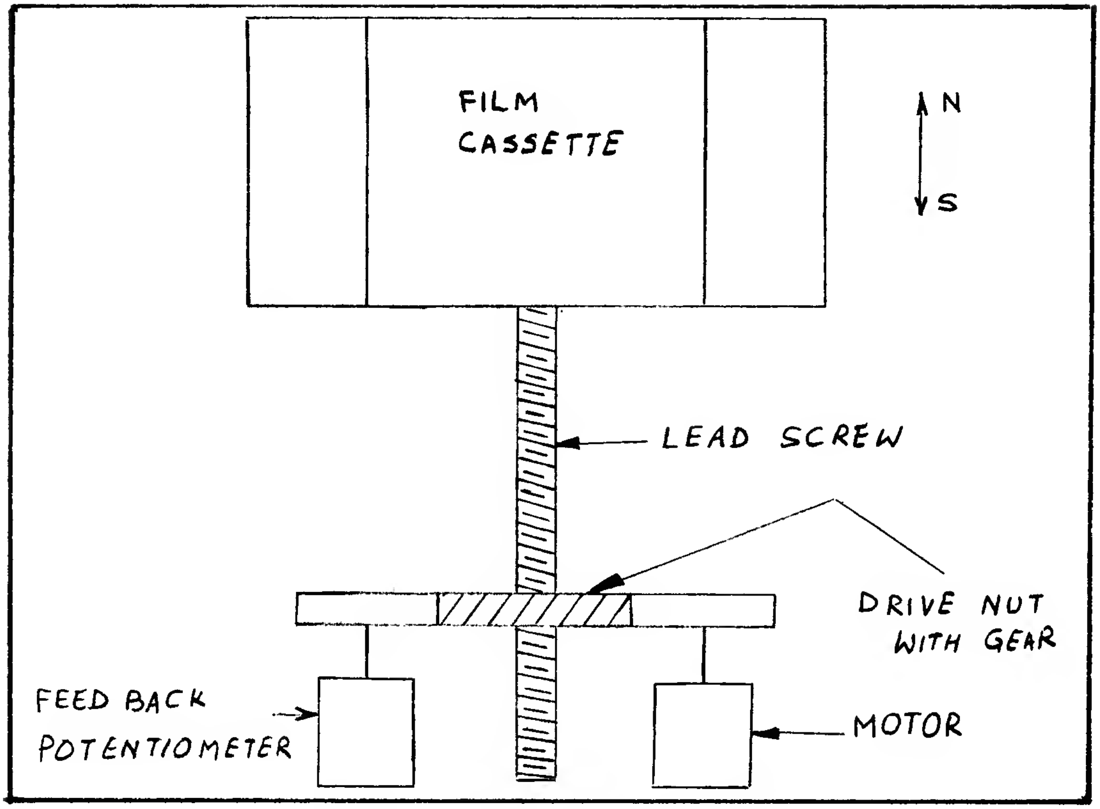


Figure C-1. North-South Cassette Drive

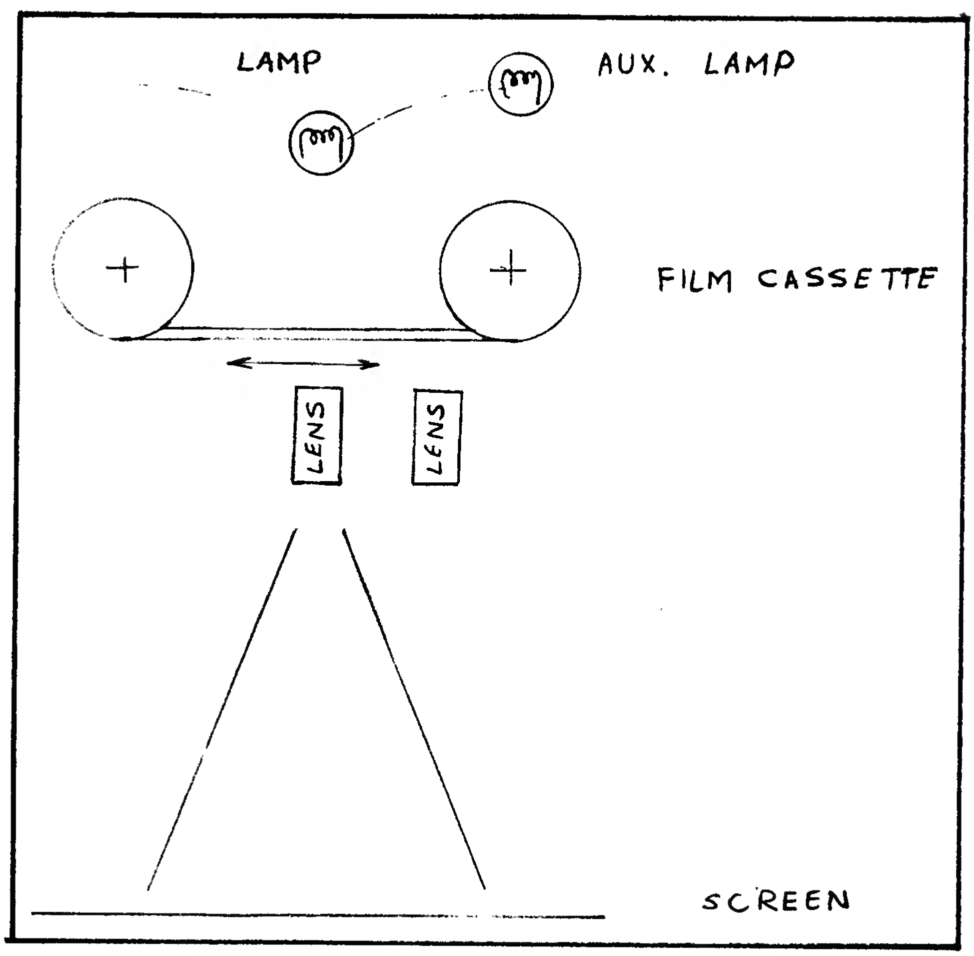


Figure C-2. Film, Lamp, and Lens System

lens system the components could be re-arranged to increase the brightness. Wing Commander Lambert was insistant that the two map scales were absolutely necessary from an operational view-point and consequently from the sales viewpoint.

When asked about these problems, Bob Vago commented, "It probably seems unreasonable to have the continuous failure of one electronic sub-system jeopardize all the work carried out to that date. It is, therefore, worth mentioning the fact that situations apparently unconnected to engineering can have an effect upon a project's success."

"The map display project was running in the order of six to eight weeks late with respect to the original schedule. Information available at the time led the Company to believe that Ferranti was going to make their model available to the R.A.F. if ComDev did not show up on time. In addition, it was understood that the R.A.F. had an aircraft standing by awaiting installation on the Com Dev equipment."

On the day that the map display was first brought together as a system, an urgent telegram was received which strongly recommended shipment of the system to Boscombe Down. The equipment was summarily packed into crates and shipped by air to the United Kingdom. Bob Vago and a field service representative were sent off on the same flight.

While enroute over the Atlantic, Bob was still contemplating a fix for the electronic sub-assembly. It was on the following day that the equipment was unpacked on a bed in the George Hotel in Boscombe Down. The following morning the equipment was to be presented to the R.A.F. An assistant from the London office of ComDev was sent out to purchase a soldering iron from a local store so that wiring modifications could be made.

"Promptly at 9:00 a.m. on the following morning the equipment and supporting team were made available to the R.A.F. It soon became apparent that the aircraft was occupied for another six weeks on other equipment trials. During the next several months no sign of the Ferranti display was seen," continued Bob.

The R.A.F. made room for the Computing Devices equipment in a small corrugated Nissen hut in which radar equipment was being serviced. Unfortunately, the skills, materials, techniques and components necessary to the map display were nowhere to be found. "On occasion, it became necessary to have machine shop work done. The nearest useable facility was sixty winding miles away in London and the supply of electronic components was limited to those available at a T.V. repair shop 15 miles away in Salisbury."

During the next four weeks the project team worked sixteen hours a day, seven days a week, to obtain satisfactory bench operation of the map display. "Frequently during this time period the electronic sub-assembly acted up and finally we had the circuit designer flown in from Ottawa to do what was possible. Once again the primitive facilities were against the project and only a limited fix could be implemented." By the time the R.A.F. was ready for flight trial of the display everything was working well except for the occasional failure of the electronic sub-assembly. It was with much trepidation that Bob and the project team looked forward to the first flight trial.

After about one week's installation

work the display was ready for trial. "The first flight went off without a hitch," recalled Bob, "and the display did all that had been hoped for. It was almost worth all the trouble to be able to recognize earth features from the aircraft by means of the map display. The accuracy was very good and the R.A.F. navigator was favourably impressed. On the journey back to base the set was switched on and almost exact correspondence existed between the map display and the TACAN set display all the way back to Boscombe Down."

After the first flight trial Bob Vago was rotated back to Ottawa. Subsequent trials were marred by occasional failure of the electronic sub-assembly. Several months later, due to low priority, the fault was cleared back at ComDev. "Unfortunately, the damage was done." The R.A.F. flight trial report issued approximately one year late commented on the fault. This same report criticized the uneven steps of the display. "The size of these steps was 1/64, which gives some measure of how subjective a display of this type can be," was Bob's response. The uneven motion was caused by the finite resolution of a wire-wound servo potentiometer. No attempt was made to find a potentiometer with better resolution while the equipment was on trial. Later trials in a Javelin aircraft involved placing the display at eye-level in the cockpit. In this position, washout of the display occurred in direct sunlight.

The trials were complete with only one major fault, the solution of which was just a matter of time.

The company was now in a favourable position for tender. Unfortunately, the Ministry of Aviation found it necessary to cancel the Hawker Hunter for lack of funds. Company's sales activity then went into low-gear and eventually Ferranti managed to persuade the Ministry to purchase their version of the Honick display for another aircraft fitment.

MOVING MAP DISPLAY (D)

EPILOGUE

Shortly after completion of the project Bob Vago left Computing Devices of Canada. The cancellation of the aircraft by the Ministry of Aviation, competition from Ferranti and an indifferent flight trial were factors which played a part in the unsuccessful attempt to get a production contract.

Bob felt, "This demonstrates that the success of an engineering project can depend upon circumstances largely beyond the control of the engineer in charge."

Computing Devices did not give up on the display. They continued a vigorous sales effort and field trials.

Three of the original development models produced for flight trials were tested by the Royal Air Force, the French Army and by the Royal Canadian Air Force.

Prepared by Professor G. Kardos with support by the National Science Foundation with cooperation and information from Computing Devices of Canada Ltd.

MOVING MAP DISPLAY (D)
COMPUTING DEVICES OF CANADA LTD.

ROYAL AIR FORCE TRIALS

The Royal Air Force trials were conducted between April, 1963 and May, 1964. For the first phase of the trials, the Projected-Map Display was installed in a Hastings transport aircraft. The system was provided with true heading and drift angle and ground speed from a Doppler radar. Principal objectives of this phase were to assess the accuracy of the display and to evaluate human factors of readability and handling, principally as a navigator's function.

For the second phase of the flight trials the Projected-Map Display was installed in a Javelin aircraft. Sensor inputs to the system were magnetic heading and true airspeed. Magnetic variation and wind velocity were manually set. The principal objective of this phase of the trials was to assess the display as a pilot navigation aid in low flying, high speed strike and reconnaissance aircraft roles.

The flight trials were conducted with some night flying at an average height of 250 feet and an average air speed of 450 knots.

The final phase of the R.A.F. trials was a prolonged bench test of equipment which included 24 simulated flights of 300 nautical miles and the cumulative results (for a sub-system of Display Unit and Analog Computer) of these simulated flights showed mean errors of 0.33 per cent along track, 0.05 per cent across track and a standard radial error of 0.26.

The first trials of a projected colour film map display provided a valuable assessment of display performance and human factors. Low altitude track-keeping ability was excellent, as was navigational orientation. Fixing capability was continuous and simple because sensor errors which caused the map to drift out-of-phase with the ground were readily detected and corrected. Map display controls have been greatly improved in design as a result of the human factors assessment in flight.

FRENCH ARMY TRIALS

The trials were sponsored by the French Army Light Aviation Group. Bench trials were conducted at SUD Aviation in 1964, and flight trials in an Alouette III helicopter during 1965.

No trials report was available; however, an operational requirement for a projected map display was introduced after the trials. Pilot debriefing following trials established the general acceptance and enthusiasm for operational ease of handling and the actual display of information, as presented.

Two significant statements made by Captain Chaillet, the project pilot, placed numerical values on the advantages of the projected map over hand-held maps. These were:

(a) the projected map enabled a reduction of crew from two pilots to one.

(b) that mission navigation success rate (i.e. maintaining prescribed

course with one kilometer at 'nap-or-earth' altitude) rose from 20 - 25 percent to 95 percent.

During the above trials development continued. Updating and improvements included reduced step size on the film drive, joystick slewing and position update, relocation of mode controls, mode lights and improvement in film frame advance.

RCAF FLIGHT TRIALS

The trials vehicle was a CF100 aircraft and tests were run in 1965 and 1966.

Evaluation included Phase 1 using heading, true airspeed and hand set wind velocity and Phase 2, using excellent sensors of stable platform heading and K band roll stabilized doppler.

Although an official report of the flight trials has not been issued, liaison has established that the display was extremely well received. Pilot comment confirmed that the development of improved brightness under direct sunlight, on which work was being done, was a definite requirement.

These flight trials showed that the film presentation concept, the basic outline of the equipment and capabilities of the design were well established. Accordingly, further development work proceeded along the original lines incorporating anticipated improvements.

Design updating included improved cooling, modified film drive, frame advance speed up and accuracy, packaging, film-type change, optical components and brightness level.

A-7 AIRCRAFT FLIGHT TRIALS

A system for flight trials was carried out by the United States Naval Ordinance Test Station, China Lake, in mid-August, 1967.

Flight testing and evaluation was conducted by VX-5 Air Development Squadron in an A-7A aircraft.

The purpose of the trials was to determine the advantages of the Projected Map Display over the paper roller map presently installed in this aircraft type.

The results of these efforts was a successful bid to equip the Corsair II A-7E with the system. George Wilaneous, Vice President of Marketing for ComDev remarked, "Our success in this case was largely due to proven capability of the system, as a result of the many field trials."

In reviewing the case history, Gordon M. Mount who acted as programme manager at ComDev during the A-7 competition stated:

"It is my opinion, that the 'non-success' of the early RAF trials was not due particularly to ComDev ineptness, which was Vago's original implication. Vago attempted to maximize his diligence, etc., but felt he was the victim of circumstance. To me, the major cause of early customer reluctance was a combination of 'the market wasn't ready,' and the engineering design clearly had severe functional limitations."

"It should be made very clear that only the broadest similarity of concept

exists between the current design and the original prototype; the present day Projected Map System is one of the more successful items of aironics hardware on the A-7 airplane."

PROBLEM	SOLUTION
1. Inaccuracy in present position after automatic frame change operation attributed to lost or spuriously gained stepper motor pulses during frame change.	Redesign of film drive system to replace stepper motor drives with servo motors and replacement of potentiometers with synchro transmitters for feedback of film position.
2. Obvious coarseness of map incremental step motion.	
3. Lengthy frame advance time.	
4. Insufficient display illumination for satisfactory viewing in direct sunlight. Note: Increasing projection lamp excitation would shorten lamp life and cause film damage by overheating.	New projection lamp operating at a higher excitation voltage, improved cooling and modified optical elements.
5. Insufficient heat removal at high altitude and high ambient air temperature accelerates film fading. (Revealed during MIL-E-5400H Class 1 environmental testing).	Redesign of cooling system to provide two blowers, one using unfiltered ambient air to cool projection lamp and the other using well filtered air to cool the film-gate heat glass.
6. Film cassette subject to up/down and forward/backward vibration modes ranging from mild to severe with sufficient displacement to cause loss of focus.	Redesign of complete film cassette and turntable to provide maximum rigidity.

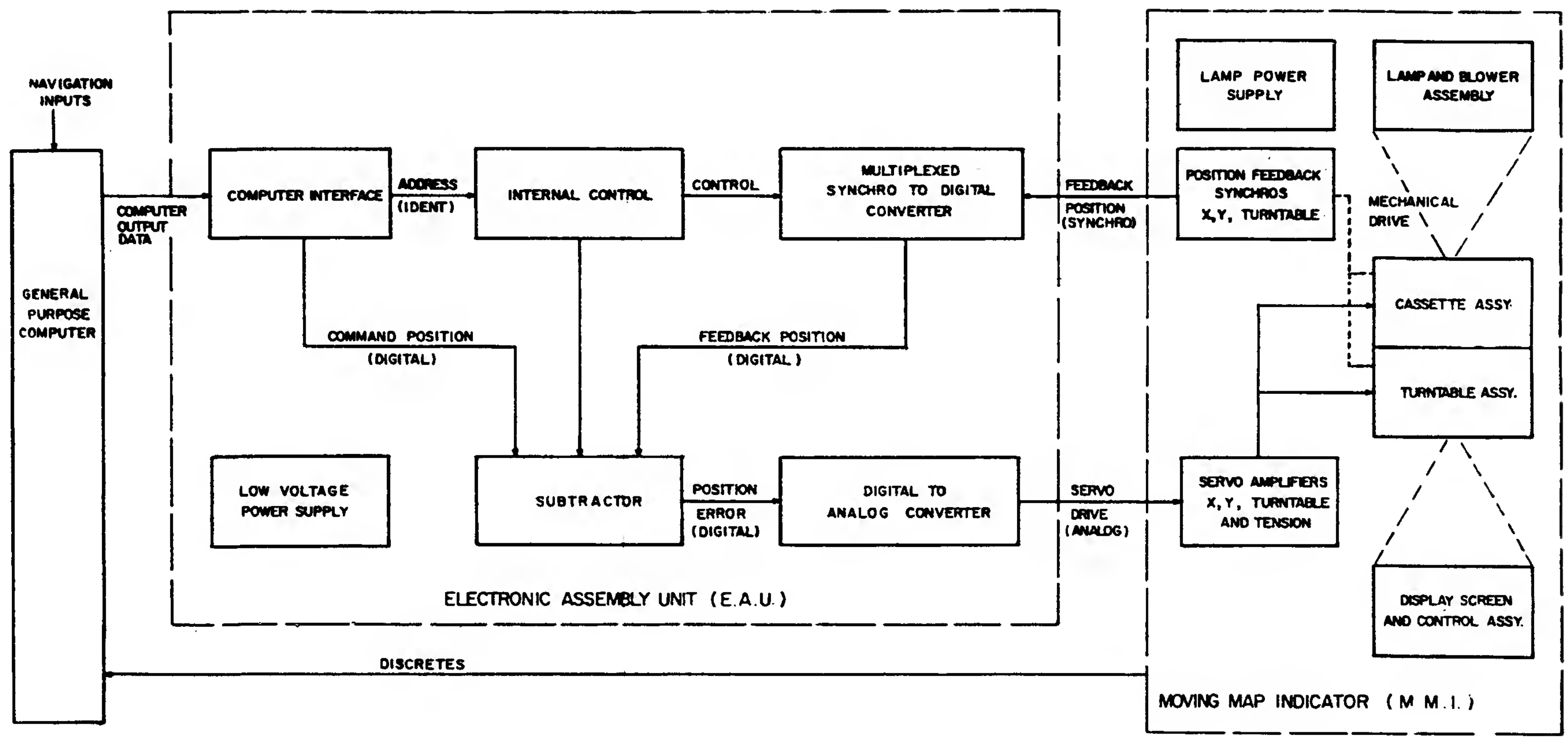
MMI Design Improvements

EXHIBIT D-1

PROBLEM	SOLUTION
7. Position resolution, repeatability of position indication and some-time erratic operation of film drive, all attributed to film position feed-back derived from potentiometers.	Redesign of film drive system utilizing servo motors and 3 speed servo feedback provides high resolution and accurate repeatability.
8. Film damage caused by dust particles	Redesigned film cassette with housing and use of filtered air for film gate cooling.
9. 'Hot Spot' or non-uniform illumination of screen as a result of increased illumination.	Reselection of projection lens.

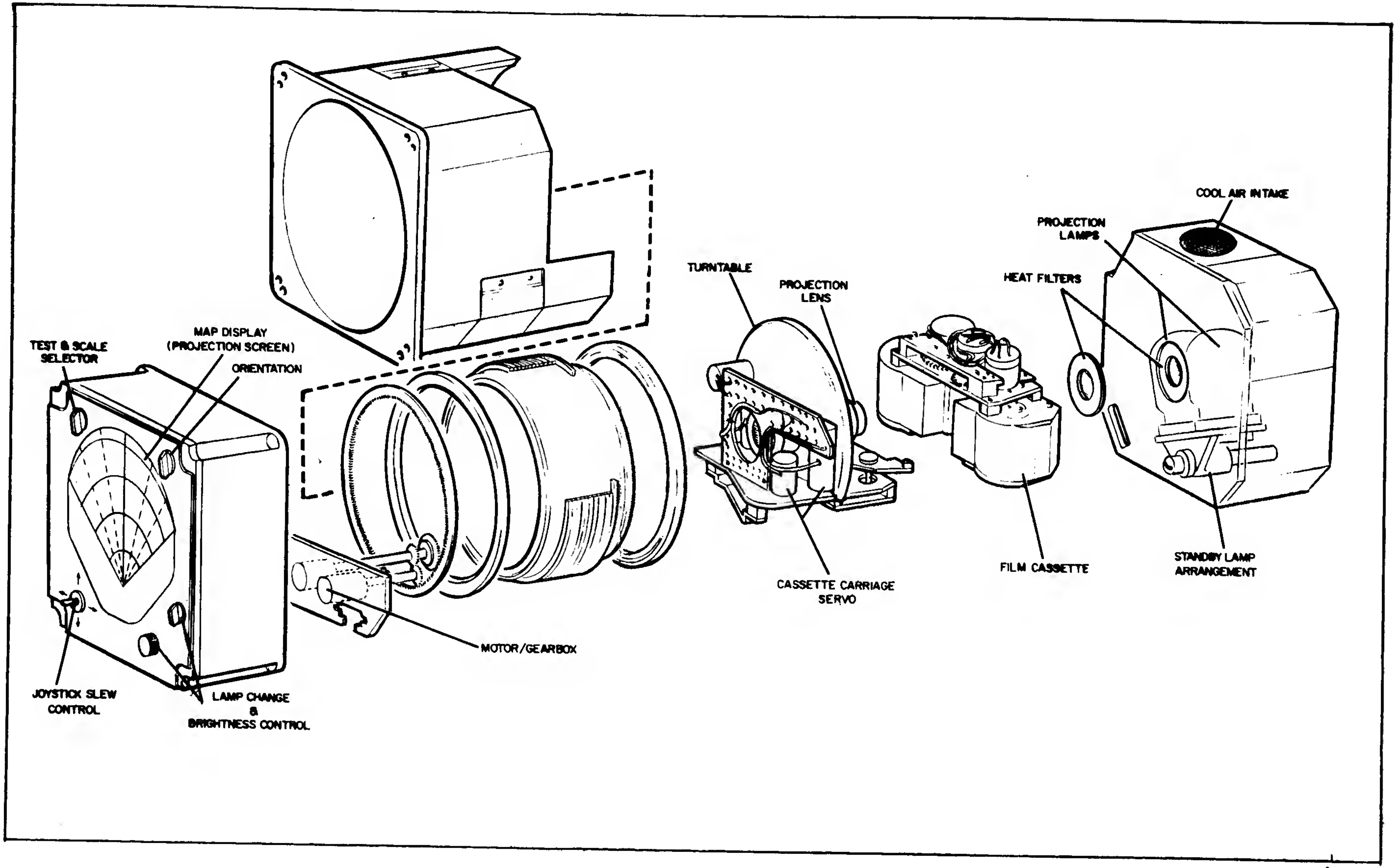
MMI Design Improvements

EXHIBIT D-1



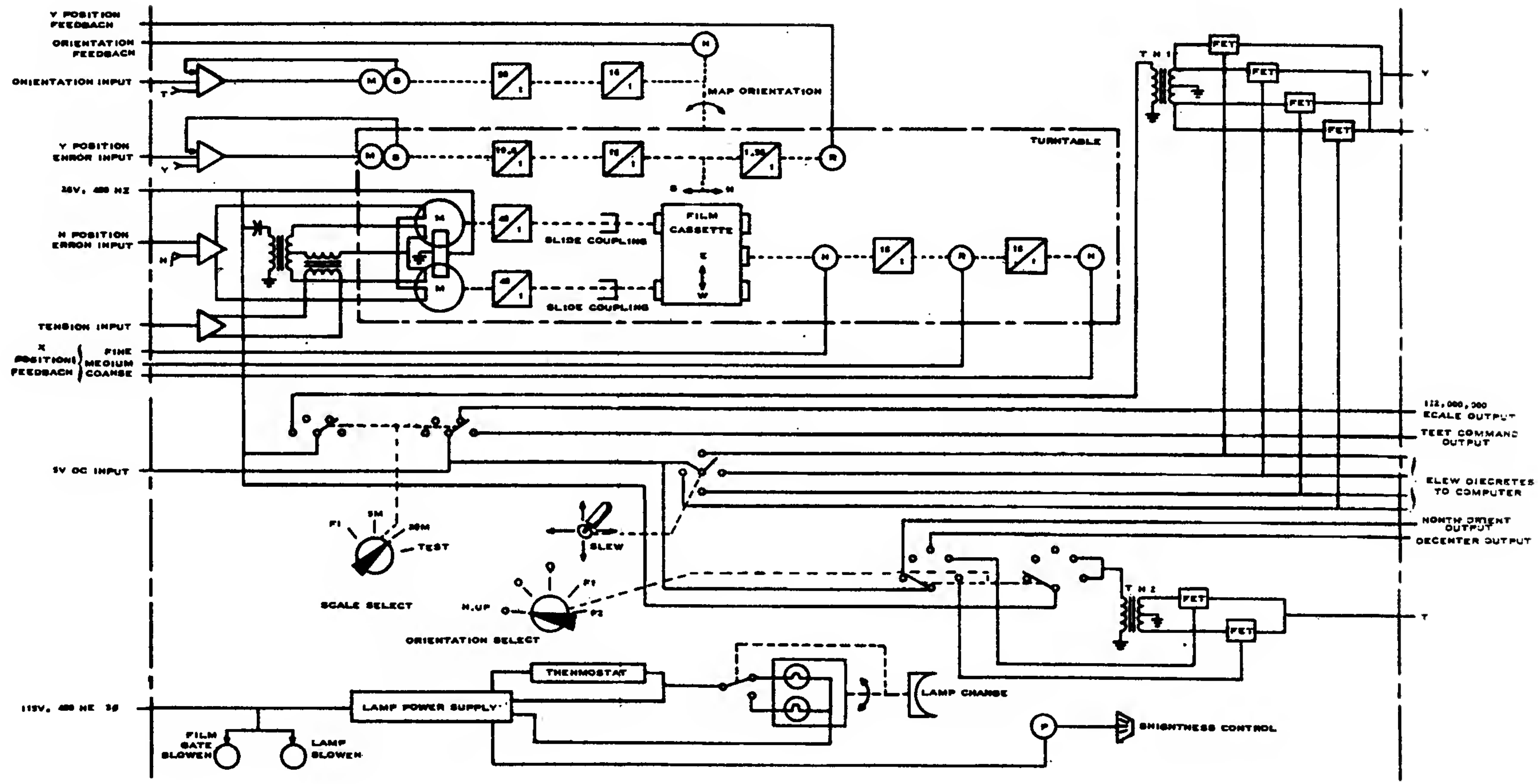
Functional Block Diagram

EXHIBIT D-2



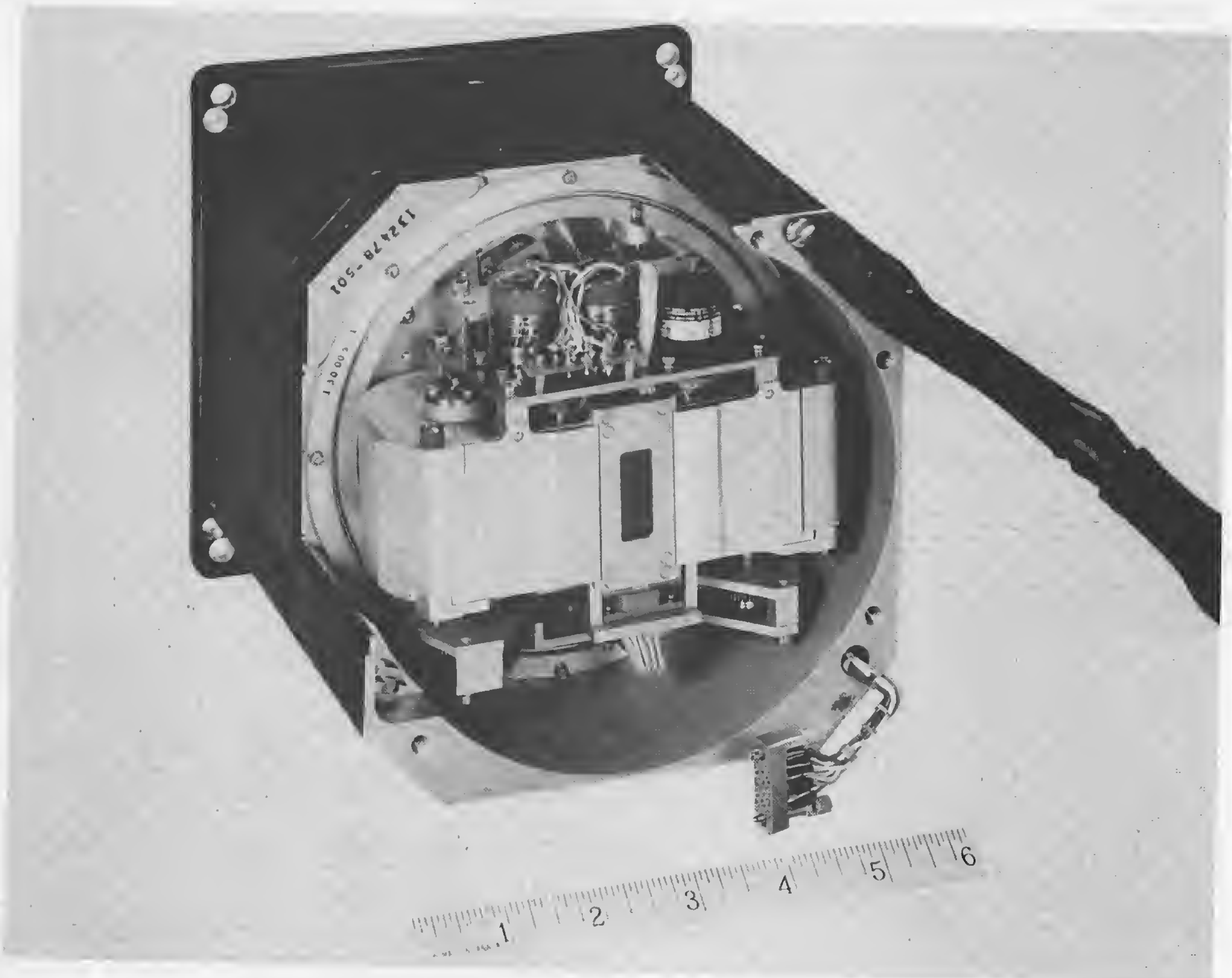
Exploded View of the Moving Map Indicator

EXHIBIT D-2



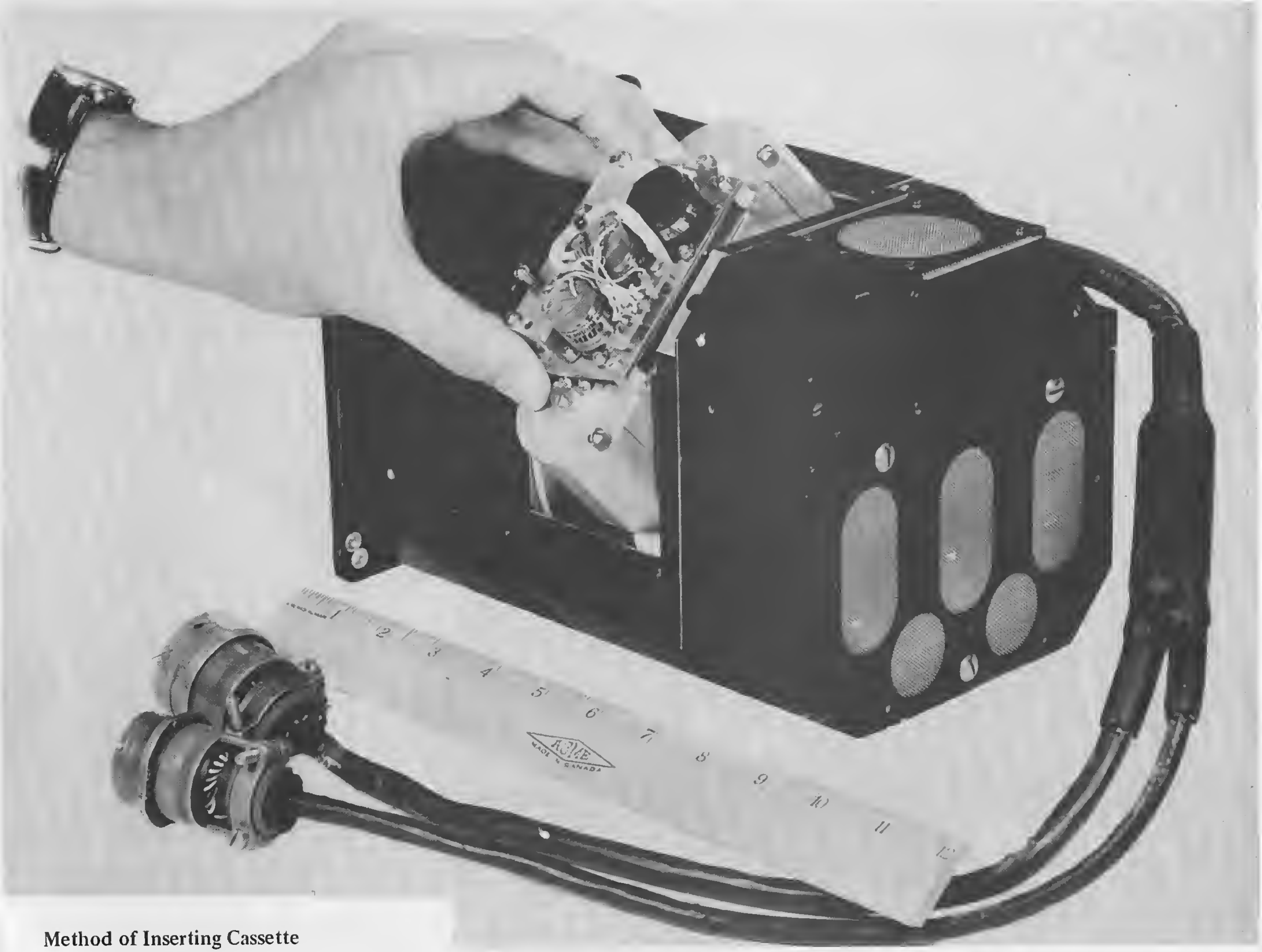
Signal Flow Diagram for the Moving Map Indicator

EXHIBIT D-2



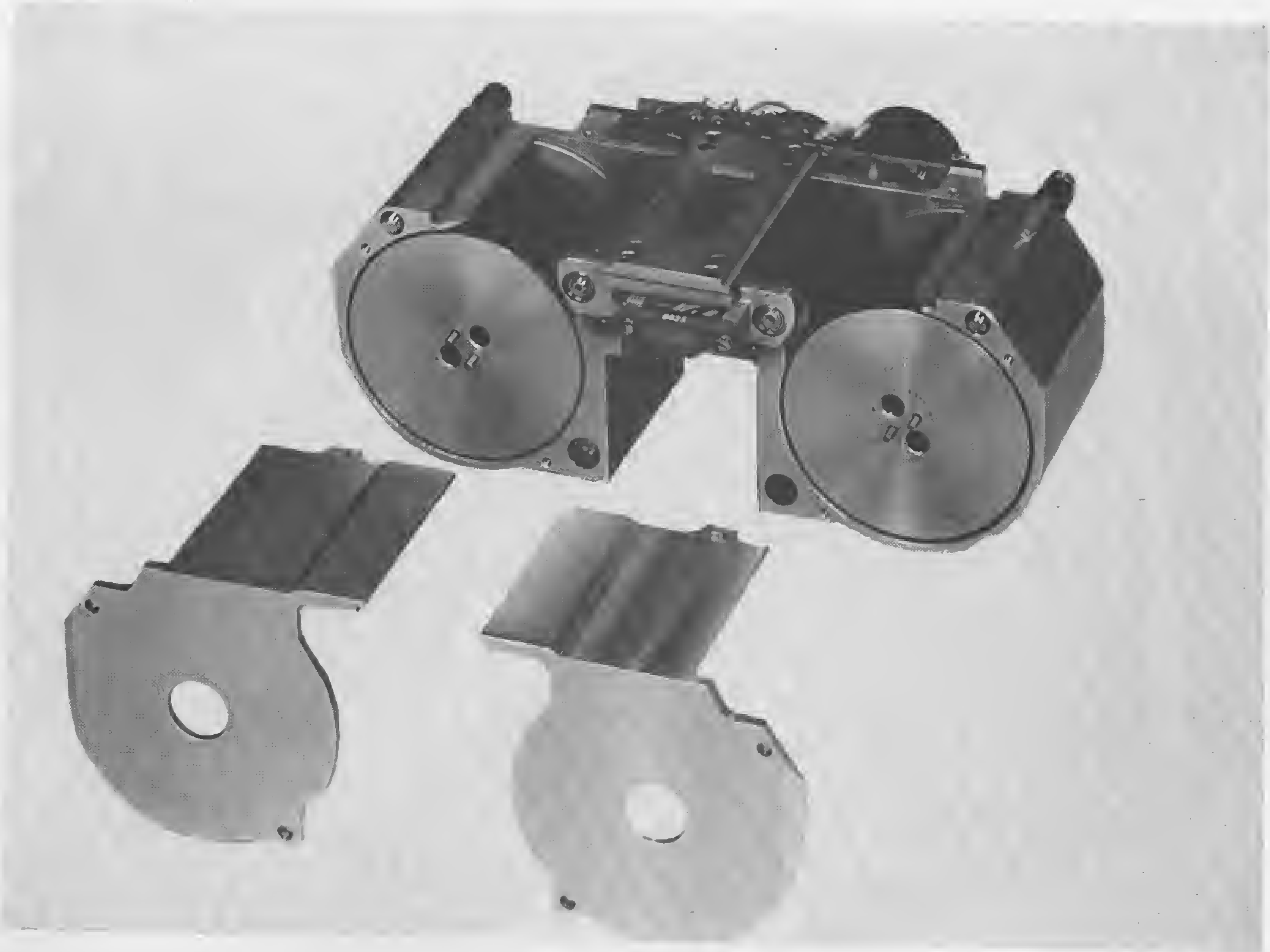
Center Section with Components Assembled

EXHIBIT D-2



Method of Inserting Cassette

EXHIBIT D-2



View of Cassette Showing Film Path